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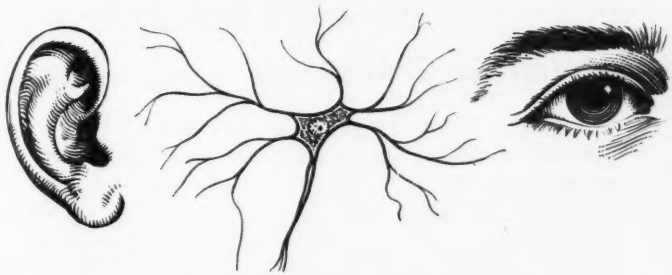

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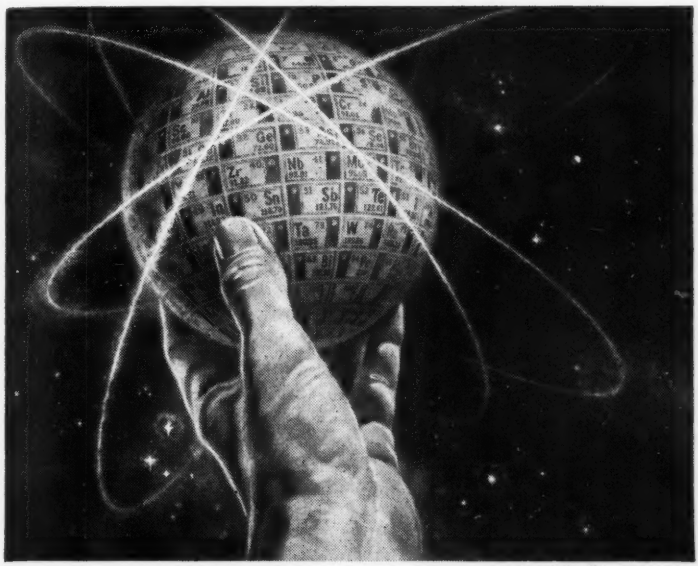

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Do You Know

► That this year's membership drive is in the hands of the Sections? A representative will be selected on each campus and he will be responsible for contacting all non-members. At present, only about 46% of full-time staff belong to ASEE. This should be doubled! Aid your campus representative by plugging ASEE to those you know are non-members. And do not forget those in English and the humanities! There will be competition and recognition of achievements—be sure your school will be recognized. Promotional literature can be obtained from your campus representative or by writing to the Secretary of ASEE.

► That the Educational Methods Division is undertaking a study in the area of faculty utilization to follow through the recommendations of the Committee on Development of Engineering Faculties? Chairman of the Educational Methods Division, Dr. W. K. LeBold, Purdue University, has announced that the Division will hold an invitational research conference on faculty utilization later this year. The Westinghouse Educational Center in Pittsburgh will serve as the site for the Conference and is providing the financial support. The Committee for planning and arrangements is: Chairman, E. K. Kraybill; Secretary, E. J. Rising; H. A. Foecke, H. W. Case, O. E. Lancaster, and C. E. Schaffner.

► That through the years 1956–1960, 581 faculty members from colleges of engineering attended the jointly sponsored ASEE–AEC summer institutes on nuclear energy? Actually, 493 different people are involved because some have attended more than one institute. The basic or beginning institutes were attended by 326 individuals and 186 have attended advanced institutes. In addition, 69 have attended the basic or beginning institutes for technical institute teachers. The number of engineering schools represented is 116 and the number of technical institutes is 40; there also have been representatives from the four service academies. Forty-seven states, Puerto Rico, and the District of Columbia have been represented. Reports on the evaluation of this program and the equipment grant program have been made and will be published in the February JOURNAL.

► That the importance of science and the need for scientists perhaps is being over sold? A news release from Harvard University states that when the Class of 1960 entered in the fall of 1956, 47% planned study in the natural sciences, 21% in the social sciences, and 31% in the humanities. Four years later, when the class graduated. the similar percentages were, respectively, 25, 47, and 28. It also is interesting to note that half of the graduating *summa cum laude* group came from the natural sciences.

► That a leasing plan for scientific instruments has been announced by RCA? Educational institutions, laboratories, and other users may rent scientific instruments such as electron microscope or X-ray diffraction equipment. It is expected that the plan will be highly significant to educational institutions depending on funds available on a year to year grant basis. There is no down payment, and pro-rated credit for part of each month's rental may be applied toward outright purchase of the equipment.

► That a new index to chart the demand for scientists and engineers in the U. S. has been developed? Deutsch and Shea, Inc., technical manpower consultants, have developed what they call the *Engineer/Scientist Demand Index*. It is based on monthly measurements of the recruitment advertising directed to engineers and scientists appearing in a carefully selected group of technical journals and leading newspapers in 20 key market areas. The actual number of engineers and scientists being sought is not shown, but a continuing measure of the recruiting programs being carried out in industry is indicated. To arrive at the index, the total number of recruiting ads published by the participating publications during a month is used to indicate the extent of recruiting activity and the total linage of the ads to indicate the intensity

of the activity. The ratio of linage to ads is indicative of the size of the advertising space used and, hence, of the amount companies are spending to reach engineers and scientists.

► That the U. S. Office of Education is making a new annual survey to determine the number of students enrolled in graduate work throughout the country in selected subjects and the progress made toward their degrees? The data for the fall of 1959 indicated that in the 572 U. S. colleges and universities granting advanced degrees the enrollment was 305,000. Only about ⅛ were studying full-time. The data are gathered for the planning and administration of government fellowship, training, research, and facilities programs. Employers also will be enabled to estimate more accurately the number of graduate students available for employment and post-doctoral research.

► That the 1960 "Engineering Graduate Placement Survey" of the Engineering Manpower Commission made a few interesting comparisons with other fields? The 82% of engineering graduates committed to jobs as of May 20, 1960, compares with 70% in business and commerce, and 73% in liberal arts and science. The overall observation is that the demand for engineering graduates continues at a high level, essentially the same as in the spring of 1959. One disappointing statistic is that the number entering graduate study remained at the 10% mark. This compares to 6% for business and commerce and 22% for arts and science graduates.

► That engineering schools spent $71 million for research and development for fiscal 1958? NSF states this is for "earmarked" or sponsored research and development. $48.6 million comes from the Federal Government, $10.3 million from industrial sources, and the direct support from their own funds was $10.5 million, plus an additional $3.5 million from indirect costs of outside-sponsored grants and contracts. 129 engineering schools participated, 20 reporting expenditures of over $1 million and 24 less than $25,000. Of the $71 million total, 57% was reported as going for basic research; the similar 1954 study indicated only 45% for the same purpose. Additional data are in "Reviews of Data on Research and Development, No. 21, Funds for Research and Development in Engineering Schools, Fiscal Year 1958." Copies can be obtained for 10¢ each from the Supt. of Documents, U. S. Government Printing Office, Washington 25, D. C.

► That the National Science Foundation now has a program of "Institutional Grants"? They are designed to strengthen the overall scientific research and research-training efforts of colleges and universities. It is not necessary to specify particular activities to be undertaken with the funds, for they are intended to complement Foundation support of science and science education now provided through research grants for specific projects and through fellowships. The amounts of grants are limited to 5% of Foundation research grant payments made to the institution during the previous year, but in no case exceed $50,000 for any one fiscal year. Inquiries should be directed to Dr. Louis Levin, Director of the new Office of Institutional Programs.

► That two engineers were among the 41 North Atlantic Treaty Organization (NATO) Postdoctoral Fellowships in Science awarded by the Department of State and administered by the National Science Foundation? There were 162 applicants from which the 41 awardees were selected. The institutions selected by the engineers are the University of Cambridge (England) and the University of Grenoble (France).

► That of the first 27 Senior Visiting Fellowships in Science of the Organization for European Economic Cooperation, four were in engineering? All four are going to England—Kings College of the University of Durham, Imperial College of Science and Technology of the University of London (and then to Portugal and Italy), University of Oxford, and the

Road Research Laboratory of the Department of Scientific and Industrial Research.

► That 10 of the 32 grants for the development of new laboratory apparatus totaling $284,450 are in engineering? Since the grantees for science teaching are expected to supply teachers with full information about the apparatus developed in journals and at professional meetings, it seems appropriate to briefly list the ten engineering projects and the names and institutions of the grantees.

1. Aids and models for demonstrating atomic and molecular relationships in the study of engineering materials. Sacramento State College, G. N. Beaumariage, Jr.

2. Vortex-tank tunnel, visual pipe network, dynamic model, and portable vibrations simulator for demonstrations and experiments on fluid and structural mechanics. George Washington University, R. R. Fox.

3. Equipment and manual for laboratory instruction in automatic process control. Illinois Institute of Technology, B. S. Swanson.

4. Still and motion pictures of compressible flow in supersonic wind tunnel. University of Notre Dame, V. P. Goddard.

5. Portable electronic analog-simulator-computer-demonstrator for introducing analog techniques in teaching. Polytechnic Institute of Brooklyn, P. N. DeCicco.

6. Transparent, flexible models for observation of internal deformation patterns in mechanics. University of Dayton, R. J. Stith.

7. Waiting-line electric-electronic model illustrating range of patterns of flow of units. Oklahoma State University, S. T. Poage.

8. Small laboratory and demonstration hypersonic wind tunnel. Pennsylvania State University, J. A. Fox.

9. Small-scale tape-control unit for instruction on automatic and semi-automatic machines. Southern Methodist University, F. W. Tippitt.

10. Laboratory instrument for student operation illustrating current-vs-voltage characteristics of electronic devices, rectifying circuits, and meter response to periodic wave forms of voltage. University of Virginia, C. M. Siegel.

► That 32 programs in engineering at 25 different schools were included in the second group of Undergraduate Research Awards of NSF? These grants for the 1960 academic year brings the total for research participation and undergraduate research training programs to about two and a quarter million dollars.

► That the American Congress on Surveying and Mapping has established its consolidated central headquarters in Room 430 of the Woodward Building, 733 15th Street, or 1426 H Street, N.W., Washington 5, D. C.

► That the Atomic Energy Commission has a new atomic energy exhibit designed to acquaint the general public with the latest developments in the peaceful uses of atomic energy? It is entitled "Atoms in Action" and consists of a series of 18 colorful panels, each approximately 30 by 40 inches. It is simple to set up and requires no attendant. If you want something new for your "open house," or whatever you call it, the display can be obtained at no cost from the Museum Division of the Oak Ridge Institute of Nuclear Studies, Oak Ridge, Tennessee.

► That 11,279 of the total of 48,486 foreign students in American college class rooms are studying engineering? These figures are obtained from "Open Doors, 1960," an annual survey of the Institute of International Education. The per cent increase in the number of foreign students was 2.6% above last year, the smallest increase in the last six years. The percentage of American students going abroad to study increased 34%! More than half of the foreign students are undergraduates. Only about 38% of the total are self-supporting; about 28% were aided by scholarships offered by private organizations, about 6% were supported by the U. S. government grants, and about 5% were supported by foreign government grants.

W. Leighton Collins
Secretary, ASEE

OFFICERS NOMINATED FOR 1961–62

The Nominating Committee met in Washington, D. C., on Wednesday, November 16 and selected the following candidates:

For **President**, one year.....Robert W. Van Houten

President, Newark College of Engineering; Member of Council, 1953–57; Vice President 1957–59; Chairman, Evening Education Division, 1952–53; Member of ASEE since 1933.

For **Vice President**, Sections East of the Mississippi, two years.....George A. Marston

Dean, School of Engineering, University of Massachusetts; Member of Council, 1953–55; Chairman, New England Section 1958–59; Member of ASEE since 1938.

For **Vice President**, Sections West of the Mississippi, two years.....Curtis L. Wilson

Dean, Missouri School of Mines and Metallurgy; Member of Council, 1952–54; 1958– ; Chairman, Missouri-Arkansas Section, 1948–49; Member, Executive Committee of ECAC, 1954–56; Member of ASEE since 1941.

For **Treasurer**, one year.....Wendel W. Burton

Employment Manager, Minnesota Mining and Manufacturing Co.; Treasurer, 1959–61; Chairman, Ethics Committee, 1957–59; Chairman, Relations With Industry Division, 1955–56; Member of ASEE since 1947.

ADDITIONAL NOMINATIONS

In accordance with the revisions of the constitution and by-laws adopted in June of 1957, *additional nominations may be made by petition* of fifty (50) signatures of members of the Society in good standing. The nominee must indicate a willingess to serve, if elected, before his name can be placed on the ballot. Petitions are to be submitted to the Secretary of the Society by January 15, 1961.

In the February 15 issue of the JOURNAL OF ENGINEERING EDUCATION ballots giving the names of all candidates will be provided. Ballots received by the Secretary by March 31 shall determine the election of the officers as of April 1. Their terms of office shall begin ten days after the date of the annual meeting.

Use of Computers in Engineering Undergraduate Teaching

DONALD L. KATZ

Professor of Chemical Engineering and Director, The Ford Foundation Project on Use of Computers in Engineering Education, University of Michigan Ann Arbor

ELLIOTT I. ORGANICK

Assistant Director, The Ford Foundation Project on Use of Computers in Engineering Education

Abstract

Concepts and progress made in introducing computers "from the bottom up" in classroom instruction are reported. This approach and the objective of integrating the use of computers in all phases of engineering problem courses is being developed at the University of Michigan College of Engineering in a project sponsored by the Ford Foundation as a means of upgrading engineering education.

The full process under development involves: 1) establishing effective means for developing the faculty with a minimum delay; 2) introducing all students to the philosophy and techniques of computing at the start of their engineering training; and 3) demonstrating accomplishments in the form of documented case studies of classroom problems wherein students use computers. Long range success of this development depends upon introduction of computer-oriented subject material in the mathematics portion of the curriculum and upon achieving an appropriate level of University support for computer equipment to be used in instruction.

A program of visiting professorships, special summer assignments and short workshops at the University of Michigan for faculty of cooperating schools is now under way. It is expected that the visitors will contribute to the project and, upon returning to their respective schools, provide leadership in similar developments around the nation.

Presented at the 68th Annual Meeting, American Society for Engineering Education, Purdue University, June 20–24, 1960.

In the Future

The widespread use of both digital and analog computers in industry and research makes it clear that the calculation effort of engineering in the future will be done by machines. Industry has shown leadership in many cases today in the development of engineering calculations by electronic computers. We often hear of the shortage of engineers for the future. It is clear that this shortage will be ameliorated by the large amount of work which will done by machines instead of by people.

Originally computing machines were regarded and utilized merely as glorified slide rules. Experience with computers has allowed us to assign far broader scope to their capability. Computers stimulate development of new methods for solving problems. The logic and structure of problems come into clearer focus when one looks at them from the standpoint of the computer. This will, in itself, revolutionize much of the work done in engineering. From their industry contacts and from their own experiences in academic research, educators have many experiences which spell out the vital role computers play in these areas.

Recently, a visiting engineer from industry was asked, "Can you conceive of

a young engineering graduate leaving a university, entering industry and not having within the first two years a problem go over his desk about which he would say, 'This is a problem for the computer.'" The man from industry said, "Why don't you say, 'in the first two months?'"

Three years ago a graduate student had completed his doctorate research on heat transfer through finned tubes in which he had taken experimental data with a large number of variables such as tube spacing, fin height, fin thickness, fin spacing, air velocity, temperature differences, etc. In trying to find a dimensionless equation to correlate the data he spent some two months with hand calculations and came up with what he thought was a reasonable correlation. Just as his thesis was going to be typed, another student who knew how to program with the regression analysis techniques asked him if he had tried this procedure with his data and he said, "No." In a twelve-hour period they programmed and processed the data through the IBM 650 and ended up with a new correlation involving different dimensionless groups that had not previously been thought necessary to consider. The new correlation is superior to that which the student had evolved over a two-month's study. Such experiences convince educators that every person working in research should have enough knowledge of computers and applications to be able to seek out and follow these procedures.

The handwriting on the wall reads plainly: *All graduating engineers of the future must have a knowledge of computers just as they have a knowledge of mathematics. Engineering calculations of the future will be done by machines.*

Place of Computers in Education

This general view of the coming of the use of computers in engineering has been in the minds of engineering faculties for some time. A group of faculty members on each campus has employed a computer to solve specific research problems, often with the assistance of graduate students. Most educators are in agreement that computers belong somewhere in the engineering curriculum. Computers, although already used widely in the colleges, have not become an everyday classroom experience.

The question is, "How to develop the educational program so that graduates have the appropriate experiences?" There are three approaches which have been or are now being tried: (1) integration with engineering instruction, (2) senior elective computer courses taught by specialists, and (3) selfteaching, such as on research projects, or learning to use it "when the shoe fits."

Methods 2 and 3 have been in use for some time. Most schools offer credit or non-credit programming courses in which seniors and graduate students may learn to use the computer for solving problems. Because of their specific requirements, students doing research find great benefits from the use of the computer and therefore learn enough to use the computer, if necessary, without formal instruction.

The result of either plan is that occasionally students turn in computer solutions when the professor expected only hand operated solutions. The professor who looks at these solutions is impressed, but can't really evaluate them because he doesn't understand them. These experiences help the professor realize that if he is going to provide any leadership for this student he must himself learn how to use the computer to solve the problem. This sort of pressure is evident to many people. It is also clear that method 1, the integration of computers with engineering instruction, would offer a more direct approach. Why not build computer theory and practice from the bottom up rather than wait for it to filter down?

This proposition was the heart of a proposal submitted to the Ford Foundation by the University of Michigan for which support was provided last October (1959). This paper is essentially a status report of the concepts and progress made in introducing computers "from the bottom up" in classroom instruction. Primary emphasis in this paper is given to digital computers.

What is needed to implement the in-

tegrated approach? It appears that engineering colleges need a jump input or step function to get on the road. Methods of teaching all engineering students are not available, nor are the faculty generally knowledgeable in the use of computers to the extent that they can teach the students. Therefore, a special input is required in engineering education to develop the situation. The purpose of the Ford Foundation Project is to determine methods by which the upgrading of engineering instruction might be accomplished by integrating the use of computers in all phases of engineering problem courses. The study is also needed to learn how this jump may be accomplished.

The training of the faculty is a major hurdle to be accomplished. A large number of faculty members are willing to go to lectures on the use of computers but somehow do not go over the hump of learning to do the job themselves. Many engineering faculty members believe they are already so busy that time is not available for them to take on new assignments of any magnitude. Others are satisfied with the indirect contact they now have with computers in their research. They hire graduate students whose knowledge of computers has permitted them to solve research problems. It may not occur to them that they could have done a better job if they had the same knowledge of computers as their student assistants. As a result of the latter situation, the impression often is given that engineering colleges are already making full use of computers in engineering education. Upon inquiry it is found that what is meant is that professors are directing research in which digital and analog computers are being used. In some cases the professors actually have computer know-how, but in the majority of the cases the knowledge comes primarily from the graduate students.

There is a vast difference between directing research employing computers and using the computers in classroom instruction. Today, some of the professors who are using computers in classroom instruction do so by bringing in outside "experts" to teach the students and they themselves are not really doing this portion of their instruction. It is believed that for the step function to have been accomplished, the engineering faculty who teach courses involving problems of significance must have a working knowledge of programming and must have first hand experience in solving problems on the computer. Faculty would then be able themselves to solve the problems which they assign their students and would be able to discuss variations in the problem solutions with students, and evaluate how well the students are doing in the work. Only then will educators know they are making the most of computers in engineering education.

Introducing students to computers properly is an important part of the study. Work is going on in several schools to find out where and how the students should be introduced to computers. Present thinking is that the students might well be informed as early as the freshman or sophomore year. The only advantage in waiting until the sophomore year is that their knowledge of mathematics is at a little higher level and the examples which can be used in the computer courses do not have to be quite so simple mathematically. There should be no gap between the introductory course and the use of the computer to solve simple engineering problems.

Demonstration of the beneficial use of computers is one way to assist in accelerating the process of integrating computers into engineering instruction. It is believed that example problems in all areas of engineering calculations would remove doubt in the minds of the faculty as to the value for students to employ computers in solving problems.

The full process under consideration thus includes the education of the faculty, methods of training the students, and demonstrated accomplishments through student use of computers.

Effort Required to Develop Faculty

The development of the faculty is a complex problem involving their attitude, competition for their time by other worthwhile things, and a reliable estimate of

the time and effort required for a given individual to go over the hump. When a man has learned to program one or two problems, and then by himself has selected an engineering problem, programmed it, run it on the computer, and analyzed the results he is "over the hump," because he can progress to problems of increasing complexity with assurance.

Only a small group of faculty may be said to approach the subject of computers with a desirable attitude. Some, to be sure, are already in the computing field and are eager to apply computers to their instructional work. Others who have had an incomplete knowledge of the use of computers tend to regard direct contact with computers as a chore for technicians and consciously or unconsciously feel that it is beneath them to "get their hands dirty" programming. Therefore, they do not propose to actually use the computer in instruction. There are others who are so busy that they say they couldn't possibly have time to learn some new discipline such as this.

Recently, a full professor said that he had enough problems to occupy his attention, that he would be too busy for the next five years, and that he couldn't possibly "get around to computers until then." The reply was made to him that probably within the next two years some graduate student would come into his advanced course and say, "Professor, . . . I think the way you're working this problem can be improved upon. . . . I have solved it on the computer. . . . Here are my results." The professor's reaction then could only be, "Gee, I just can't wait any longer. I must learn to program. . . . Why didn't I start when I had the invitation?"

One of the needs is for the faculty to get a realistic view of the effort required for them to master the situation. Some men appear to be standing off from the use of computers because they do not understand the amount and kind of effort that must be put in. In many cases the amount of effort is not such as to interfere seriously with other activities. To this end, some experiences we have had might be beneficial.

In the spring semester of 1958–59, the Department of Chemical and Metallurgical Engineering decided that each professor teaching a problem course would invite his students to attend a voluntary lecture and that the professors themselves would attend the lecture. In addition, the professors would each find one problem in the course which would be appropriate for solution on the computer and they would present this problem to the students and carry through a computer solution. An associate professor in our metallurgical group was one of the people who participated in this program both in a class in thermodynamics and in a course in metallurgical processing. As a normal part of his teaching effort he developed a problem in each of his two courses and carried the solution through on the IBM 650 computer.

During the summer of 1959 he was employed by a large research organization on the West Coast. By the end of the first or second week of his employment, reflecting upon a problem that he and his associates were trying to solve, he said to his associates, "This is a problem that should be solved on the computer!" His associates said, "Well, show us how?" and he said, "Do it this way!" and he sat down and programmed the problem. It turned out that the IBM 650 computer which this company had was of a different configuration than the one at the University of Michigan, and he had to study the differences in the two machines in order to work the problem. However, within a short period of time, and with the help of the Computing Center, he solved the particular problem in question. Thereafter, many problems were brought to his attention by his associates and he spent some 40% of his total effort during the summer as a "consultant" on the use of computers to the particular group with which he was working.

Thus, we may infer that a young man, knowledgeable in the field of mathematics, but with no prior working experience with a computer, can, with a reasonable effort, learn enough both to teach the subject and to make beneficial use of it in engineering calculations.

Experience in Training Faculty to Program

There are two aspects to putting faculty members "over the hump." The first is the information which is made available in the form of lectures or notes. The second is the individual effort put forth by the faculty members.

Most schools have courses on computer programming for upper classmen or graduate students, often audited by faculty members. It is customary for computing center personnel to give a series of lectures, for faculty and students in condensed form—usually ranging from 6 to 15 hours. Reference manuals for the computer are always available to augment lecture material or permit self teaching. It is believed that a large fraction of the engineering faculty members have voluntarily attended lectures of this type. However, this activity alone does not put the typical professor "over the hump." It takes an additional individual effort in programming.

The critical part of the learning process is the actual programming experience done by the individual himself. It is imperative that the professor have the experience of taking a problem, however simple, and seeing it through to a solution by the machine. The language by which he communicates with the computer, learned in lectures, must now be employed. Only in using the language has he demonstrated his understanding of it and gained the confidence that he can now teach the procedure to others.

The question might be raised as to why a larger fraction of the faculty have not proceeded to obtain programming experience. Admittedly, the time required is a factor. However, the real deterrent is likely to be the uncertainty that a reasonable effort on his part will give him an ability to solve problems of significance.

One answer to this problem is to have a situation in which it is necessary for the professor to meet a time schedule and at the same time provide him with someone to answer authentically any questions which may arise. The individual's background is important at this point.

Experience indicates that younger men with a reasonable facility with mathematics can learn to program with an individual effort of 15–20 hours. It follows that a one-week short course completely devoted to lectures and individual work is enough for such persons to be on the road, provided continuing experiences occur following the intensive study.

Experienced teachers, somewhat removed from their student days, may prefer a step by step approach to the problem, such as is afforded during a summer period or semester. They are more satisfied to explore the material and to find their own methods for solving the problem. This extra time permits study of the application of the computer in the individual's teaching area.

The Ford Foundation Project provides for both mechanisms mentioned—a week's intensive course and a summer's or semester's study. A mechanism for faculty to learn programming is to have them assist in teaching the introductory computer courses to undergraduate students. During the past semester, three engineering professors with no prior experience with computers handled recitation sections in a one-hour course (Math 73) for which lectures were given by a computing center mathematician. By providing auxiliary assistance to these teachers, and conscientious effort on their part, they were able to go "over the hump."

Effort Required to Educate the Student

To start students on the road to computers it is believed that a special input should be made, such as a course in either the freshman or sophomore year, which is directed toward the understanding of digital computers and toward a beginning experience in programming. At the University of Michigan it was decided that the first semester of the sophomore year would seem to be a good place because the students would have had enough mathematics to handle problems involving calculus. The extent and content of the introductory course needs to be considered.

Philosophy Versus How to Do It

In a recent conference [1] we discussed the introduction of computers to students and a strong plea was made for giving computer appreciation material to the students. In this way they would develop the logic and the understanding of the structure of problems as a general philosophy of engineering early in the curriculum. It was believed that this introduction should spend a good deal of effort on philosophy before they got to the "how to do it" phase. The question is whether they should have philosophy first and later the "how to do it" or whether they should learn the philosophy as they proceed with the actual solving of problems. Naturally, there is pressure against putting a large block of time into the use of computers because undergraduate programs are already overcrowded, and it is necessary to take out such time either from other required courses or from electives. A factor in deciding the minimum time allotment is the advances made in languages for communicating with computers.

Languages and Programming

Digital computers are machines which must be given detailed instructions for performing very simple arithmetic and logical steps. Instructions of this type, known as machine language instructions, may be required by the hundreds even for relatively simple problems. Computer experts have recognized that the solution to any problem can be expressed as a procedure or algorithm each step of which involves certain fundamental operations which are already familiar to us. These operations are not necessarily the same as the simple steps made by the machine. However, each fundamental operation can be equated to a group of machine instructions or building blocks. Consequently, the computer expert has been able to mechanize the process by which a problem procedure, utilizing these fundamental operations, can be converted into a set of instructions for the machine. This new means of communicating with the machine is called a problem-oriented language and the mechanization is often called translation.

The programmer thus may learn with relative ease a language for communicating his procedure to the machine without becoming familiar with the machine language.

Startling progress has been made in development of programming languages such as Fortran developed in 1956 and MAD developed in 1960. For scientific and engineering calculations a universal programming language is now available called *ALGOL*. A person may learn to utilize computers more effectively and with less effort when using these languages as compared to machine language.

For any computer, a spectrum of languages is available varying from machine language to the most advanced problem-oriented programming language such as MAD. It is believed that the most advanced (most general) programming language available should be taught to the students. This experience places emphasis on the structure of the problems in contradistinction to coding techniques.

Time Allotment

It is possible, when students are exposed at an advanced level, to get the students on the road by giving a series of four, six or eight hours of lectures plus the solving of problems in their regular classes. However, experience today would indicate that a regular course lasting over a 15-week period is necessary when starting at the sophomore level. Such a course should be followed by engineering courses in the next semester in which the computer is used to solve problems.

Currently, our sophomore course (Math 73), a one-credit-hour course consisting of one lecture and one recitation period per week, is being adopted by several curricula (Table I). The lectures for this course are being given by the computing center mathematician with a balance between philosophy and "how to do it." The multiple recitation sections are taken in a good part by engi-

[1] *Conference Report on the Use of Computers in Engineering Classroom Instruction*, sponsored by The Ford Foundation Computer Project at The University of Michigan, April 29 and 30, 1960.

TABLE I

OUTLINE FOR A ONE-CREDIT-HOUR SOPHOMORE COURSE IN COMPUTER PROGRAMMING

(Math 73)

Instructor: Bruce Arden

INTRODUCTION TO COMPUTING TECHNIQUES

1. Discussion of mathematical notation
   a. Single variables
   b. Linear and higher dimensional arrays
   c. Compact summation and product notation
   d. Polynomials
2. Analysis of the manual procedure in handling the example problem $z_i = x_i^2 + y_i^2$, $i = 1,2, \ldots, 100$
   a. Instructions
      (1) Arithmetic–scientific versus fixed decimal notation
      (2) Logical–decision steps
   b. Storage
   c. Control or execution of instructions
   d. Input-output–introduction of information into and out of the computing procedure
3. The automatic implementation of the necessary computing elements with specific reference to the IBM 704
   a. Schematic diagram of a digital computer
   b. Word structure
   c. Storage
   d. Input-output
   e. Control
   f. Arithmetic–discussion of number system with emphasis on binary and octal representations
4. Coding the example problem in machine instructions
5. Comparison of machine coding to algebraic statement of problem
6. Introduction of algebraic language–MAD
   a. The example problem is written for machine without formal explanation of language
   b. A subset of the MAD language is formally described–statement by statement–with examples
7. Numerical methods
   a. *Solution of equations by Newton-Raphson method.* A geometric interpretation is used with emphasis on the possibility of non-converging iterations. A complete example including flow charts and MAD statements is presented. The solution of a transcendental equation by the Newton-Raphson is assigned as a problem to be solved on the computer at this time.
   b. *General interpolation.* The Lagrangian form of interpolation polynomial is developed by considering the familiar "table look-up" procedure and then proceeding analogously for three points, four points, etc. The evaluation of the formula illustrates the use of compact array notation and iterative statements and an interpolation problem, using the Lagrangian form, is assigned for solution on the computer at this point.
   c. *Solution of simultaneous linear equations.* In preparation for the topic of approximation, the solution of simultaneous linear equations by the Gauss-Jordan method is introduced by first going through the step-by-step reduction of a system of three equations and then repeating the procedure symbolically to develop the general formula. A complete example including flow charts and MAD statements of the Gauss-Seidel solution of a system of linear equations is presented.
   d. *Polynomial approximation.* Least squares criterion is introduced by means of graphical examples. Considering a second degree polynomial, the normal equations are derived. The extension to higher degree is indicated. Emphasis is placed upon the systematic iterative computation of the coefficient matrix. Using the same set of points that were used in the interpolation problem, a problem is assigned to

TABLE I—*Continued*

construct and evaluate at several points an approximating polynomial by the least squares procedure.

e. *Numerical integration.* The second and third degree Lagrangian interpolating polynomials are integrated to obtain trapezoidal and Simpson's rule. Numerical examples are used to illustrate the error in this type of approximation.

f. *Error estimates.* The expression of an arbitrary function as a polynomial and an error term is introduced by developing Taylor's expansion for a polynomial by successive differentiation. An expression for the error term is found and evaluated in some numerical examples.

g. *Divided differences.* The divided difference interpolating polynomial is developed in an analogous fashion to Taylor's expansion. An error estimate is developed by analogy. A numerical example is considered. A complete example including flow charts, MAD statements, data, and results of a general divided difference interpolation, with error estimate, is presented.

neering professors. In fact, this concept of lectures by computer center personnel with recitation work sessions under engineering faculty appears to be a happy solution to the educational problem.

A three-hour course in computation (Math 173) at the senior or graduate level is continuing for those wishing to have a more thorough treatment of the subject or to become computer specialists. Likewise, intensive lectures on programming were given for advanced students who were too far along at the time the project began. Over 750 students and faculty were exposed to computer programs in the spring of 1960 in this way. However, in the "bottom up" approach, the one-credit-hour input is being tried along with continuing work in subsequent engineering courses.

Engineering Classroom Use

It is believed that if students are introduced to computers with a course in which both the philosophy and the "how to do it" are given them, they then should, in regular engineering courses, start solving problems with increasing complexity. In his entire undergraduate program each student should have personally solved no less than 8 to 16 problems on the computer besides becoming acquainted with the computer solutions of many other problems. Upon reaching their senior year, students should be handling problems that would not be considered feasible without the use of computers.

In the first engineering course which incorporates a computer problem, it may be difficult to find satisfactory examples. The time required to solve the problem on the computer may well exceed that for hand solutions. It will be normal for students to require additional help on the programming. The net result will be some sacrifice in ordinary material given in this course. Likewise, in subsequent courses, the same condition will apply to a lesser degree. In the junior year the computer assignments ought to emphasize the engineering aspects of problems which require such mathematical attainment as the handling of linear systems of algebraic or differential equations and other finite difference methods. The senior assignments should involve design of equipment or structures, simulation of processes and optimization of systems. With a four-semester sequence of solving problems on the computer behind them, the imagination and knowledge of the instructor, mathematical attainment and computer capability are the only limits foreseen on the problems the students can solve.

A considerable adjustment will be required in many areas of instruction. Often the professor finds that his material is not really ready to be considered for exploitation by computers. His theory has not had the generality which will permit the computer to be used to its maximum advantage. Often assumptions have been made in the previous methods which no longer need to be made and, therefore, the theory has to be reorganized. Likewise, the data used in the problem may not be either complete enough or in form which the computer

can readily pick up and use. Experience has shown that much of the work required in adapting the computer in instruction is the assembling of the data in digital form. It will be a long time before the source material for teaching obtained from books, articles, etc. will contain the theory and data in form suitable for convenient use with computers.

Example Problems Needed in the Short Term

It is clear that there is a need for developing simple documented engineering problems adaptable to solution by students on the computer. Our faculty are being encouraged to conduct case studies in their courses with computer problems. The Appendix gives the results on one such study by Professor D. F. Rudd in a rate processes course for juniors.

To assist the faculty, an outline for conducting a case study was prepared. Rudd's report follows an outline developed expressly to assist the faculty in the conduct of these studies. It is expected that at least 10 such examples will be completed this summer and incorporated in the annual report on our project. These problems are believed to be of temporary value in that the typical teacher in due time will develop his own problems with computers once he has acquired some computer experience.

A variation of the above procedure to handle example problems is that of bringing in an expert in programming to solve a class problem the professor would like to assign his students. The professor can learn the effort required to solve the problem and have a computer solution available to show his students. In the next semester, the professor may assign this problem, or a modification thereof, to his students for them to solve on the computer. Such a procedure will be helpful in accelerating the process of integrating computers in instruction.

Professor E. H. Young assigns a heat exchanger design problem to his senior class and has believed it could be solved advantageously on the computer. However, he did not have the time or programming experience to try solving it and, therefore, was reluctant to assign a computer solution.

Mr. Brice Carnahan, a fourth year graduate student in chemical engineering and teaching fellow in the Computing Center, was assigned the task of solving the problem on the IBM 704 computer. He made a time study of his effort to produce an economic design for the air cooled fin tube heat exchanger (Table II). It was learned that the actual programming time was minor. The decision to set up and perfect the computer solution in printed report form doubled the overall time requirement. The time spent by Mr. Carnahan indicated that students would have required more time to solve the problem with the computer than now allowed for a partial solution by the students using slide rules. However, if the aim of the problem were modified to be that of illustrating the use

TABLE II

TIME STUDY ON AIR COOLED HEAT EXCHANGER DESIGN FOR SENIOR DESIGN COURSE

	Hours Spent by Mr. Carnahan
1. Problem definition: Listening to the instructor, reading articles furnished, selecting names, modes and units for the variables. Establishing relationships for physical properties of air, costs, etc.	6:35
2. Programming in the MAD Language: Outlining the program, block diagraming and writing program statements.	1:45
3. Clerical (Punching cards, etc.).	:50
4. Testing program: Correcting errors after first and second pass through the computer.	2:00
5. Preparing report to instructor on what was done.	7:00
6. Optional additional effort for producing elegant report-like output directly from the computer. Required large number of carefully written output statements and format declarations.	14:15
Total IBM 704 Computer Time Used Testing Program	16 minutes
Execution of assigned problem	2 minutes

of a computer in engineering design, the additional time allotment could be justified.

Adjustments in Mathematics Requirements

It is known that when the use of computers has been integrated into engineering instruction there will be pressure to adjust the mathematics required. One extreme statement which has been made is that much of the calculus now taught will have very little use in engineering calculations of the future. In any event, a radical revision of the mathematics given undergraduates will be needed. A case in point is that in the field of statistics. It has been a hard long road in trying to get statistics to be given in the regular mathematics sequence. Many people are not satisfied with what has been done to date. In the extreme, it might be said that statistics is such a special branch of mathematics that the average mathematics teacher is unwilling to teach it in the regular courses and therefore it must be relegated to special courses. In a sense, such topics as finite difference calculus, matrix algebra and numerical analysis needed in digital computations could be said to be in the same category. However, it appears that pressure will be required before these subjects will become part of the normal mathematics material given to undergraduates. The question to be answered is, will the average mathematics teacher be willing to include this material or will there have to be special supplemental courses in mathematics to equip the students for digital computation.

It would seem that the engineering faculty should get their own house in order and be on the road to the use of computers in instruction before suggestions for changes are made to mathematics departments. It is expected that the changes in the mathematics curriculum will evolve as needed.

Equipment

There have been many discussions as to the kind of equipment which engineering colleges should have. In general, people wish to do research on the same computer on which instruction is carried out. Therefore, wanting the best, most rapid, and most versatile machine that can be afforded would seem to be a good policy.

Consideration on the project is being given to the use of smaller machines as a way which people who would be slightly timid in approaching a large machine might be introduced to the use of computers. Also, it is a way by which those who first work in the field of computing may actually have the satisfaction of punching the buttons. The people who already have punched buttons don't think there has been much merit to it. Those who have never had the chance to punch buttons aren't sure until they have punched them. A Royal McBee LGP 30 and a Bendix G-15 computer, both considered "small-scale machines," are available to faculty and students through our project. However, the primary volume of student computer problems is presently handled on the large-scale IBM 704.

Eventually each school must select appropriate computer equipment of its own to be used in engineering instruction. At such a time it will be advisable to measure the capabilities of current computers of, say, the large, medium and small scale varieties against the requirements of the job they will be expected to perform. Such an analysis is illustrated in Table III for a hypothetical engineering college with an enrollment of two thousand undergraduates and four hundred first year graduate students. Computer utilization in hours per day is "guesstimated" based on current experience on the plan for a minimum of eight problems to be solved on the computer by each undergraduate for schools considering either one large, several medium or many small scale computers. In arriving at the above figures, some consideration was given to the fact that the size or scope of the problems tackled by students will tend to be limited in the senior and graduate levels when handled on the smaller computers.

It is clear that budgets must be revised in engineering schools to include substantial amounts for computing equipment. One dean said, "Please come to lunch with my President and tell him that in the past we have thought of the budget

TABLE III

PROJECTED COMPUTER USE IN INSTRUCTION FOR HYPOTHETICAL ENGINEERING COLLEGE
(2,400 Students)

Year	No. of Students	Problem No.	IBM 704		IBM 650		LGP 30 or Bendix G-15	
			Computer Time per Problem per Student, Minutes	Total Hrs. per Day	Computer Time per Problem per Student, Minutes	Total Hrs. per Day	Computer Time per Problem per Student, Minutes	Total Hrs. per Day
Soph	500	1	3		15		60	
		2	2		12		45	
		3	4.5		21		120	
				.42		2.1		9.8
Junior	450	4	3		30		90	
		5	5.1		45		90	
		6	7.5		80		160	
				.61		6.0		13.1
Senior	350	7	9		90		240	
		8	18		225		400	
				.82		9.5		19.4
1st Grad	400	9	36		240		480	
		10	36		720		1200	
				2.50		33.4		58.4
Total	2,400*			4.3		51		101
No. of Whole Computers Indicated				1		4–5		10–12

* Includes 700 Freshmen not involved in computer usage.

of an engineering school as composed of buildings, faculty, and laboratory equipment; and in the future we will think of the budget for engineering colleges as composed of buildings, faculty, equipment and computers." In industry they have found that they must allocate a portion of engineering or research budgets to computers, and likewise for universities it is rather clear that substantial amounts of support must be given to computing centers for use in education. In fact, one can say that a major deterrent over the past ten years on the introduction of computers into instruction has been the financial requirement. Only in the last two or three years have many schools found it possible to provide the necessary finances for handling classroom work.

With a few more years of experience in the use of computers in instruction, it is likely that the conclusion will be that the largest and most versatile computer which can be afforded, possibly with multiple consoles, will be the best for academic use as well as research.

The College Program

The entire college, not just one or two individual departments, should adopt the philosophy of computer use in instruction. Experience to date has indicated that it would be difficult for say, two departments, such as Civil and Chemcial Engineering, to have their own students learn to use computers for working class problems and expect satisfactory integration with the regular work. If the other departments did not go along with this concept, in a short time one would find that the matter of service courses such as Fluid Mechanics, Thermodynamics, and

Strength of Materials would involve the use of computers; and the programs not accepting the principle would find that their students either would have to take different courses or would have to be prepared to understand such computer work in these service courses.

For this reason the project attempts to cooperate with other schools which are also giving serious thought to an across-the-board approach. The project issues invitations to these schools to send people to learn the use of computers either during a semester, during the summer or for a one-week intensive workshop. Approximately five men are so far promised each semester, twenty for the summer, fifty for the workshop. In looking the matter over, administrative officials find it difficult to release people for an entire semester and sometimes even for a summer because of the difficulty of replacing the teachers. The time is here when engineering colleges may need to think in terms of having their faculty spend a portion of the time learning new things by being sent off to other places or by being removed from some teaching functions in order that they may be given schooling opportunities in given areas. The use of computers in instruction is one such area by which this program could be started.

More specifically, it is believed that a college needs to have at least two or three people in each program or department who have a working knowledge of programming and the use of computers before they can be on the road to finding out how the curriculum should be adjusted to accomplish the total integration process. This means that the professors who are using the computer in research must extend themselves to understanding it well enough to use it in instruction. It also means that others who have only been talking about it must now get down to cases, really learn how to do it so as to qualify to teach with the aid of the computer. Once a small group in each department has learned enough about computers, appropriate curriculum adjustments can be made and others can learn by sharing sections with those knowledgable in the field, thus developing a rather complete knowledge on the part of all the staff.

The accomplishment of this goal is a real challenge. Even with the assistance of our Project it will take one and possibly two more years before we have an integrated program. Encouragement and commendation are due to many teaching faculty who have been contributing their efforts toward upgrading engineering education.

Acknowledgment

Members of the Computer Committee of the College of Engineering listed have made many contributions to this program: R. C. F. Bartels, R. M. Howe, D. H. Wilson, N. R. Scott, F. H. Westervelt, B. A. Galler, G. V. Berg, D. R. Mason, G. L. Gyorey, W. P. Graebel, G. L. West, R. C. Wilson, and D. L. Katz (Chairman). Support given the work by the Ford Foundation is acknowledged. Likewise, visits with faculties of many schools have been helpful.

APPENDIX A

The Response of Students in Science Engineering 112 to a Class Computer Problem

DALE F. RUDD

1. Introduction

In the spring of 1960 a class in rate processes was assigned a home computer problem. This report contains the students' background, their response to the problem and the instructor's critique. On the whole, the students' performance was more than adequate with the majority showing high interest and many great ingenuity. Several students were motivated to work additional problems in their own fields of interest.

This experience indicates that it is possible to profitably integrate a computer problem into the normal content of this course. It also uncovered some pitfalls that may be encountered and can easily be eliminated.

2. Class Background

Science Engineering 112, Rate Processes, four hours credit, is taught at the junior and senior level. The course includes fluid flow, heat transfer, mass transfer, chemical reaction kinetics, and related rate processes. The students tend to be strong in mathematics and the sciences but have less background in practical engineering courses. In some cases this course is the first exposure to realistic engineering problems.

This class of approximately fifty students meets for one hour, four days a week. Two hours are spent on formal lectures and for the remaining two hours a week the class is divided into two recitation sections. In the recitation sections, class problems are discussed and related material is presented in a less formal atmosphere to give the students closer contact with the instructors. This semester the course was taught by two members of the department of Chemical and Metallurgical Engineering: J. L. York and D. F. Rudd.

This class contains the complete spectrum of computer experience. Some students had no prior computer experience while others have worked as many as 15 problems on the computer. The one saving feature is the fact that the "problem oriented" MAD language used at the University of Michigan can be learned quite easily. The primary source of computer experience for the students was a series of evening lectures given by E. I. Organick of the Ford Foundation Computer Project. Over 80% of the class received all of their programming experience from this series of lectures totalling six to eight hours. The remaining 20% of the students completed Math 173, an intensive three-credit-hour course in computer programming and theory. One student had industrial programming experience. A condensed MAD programming manual was available to all and attendance at E. I. Organick's lectures was recommended but not required. Table AI summarizes the class background. This class is a cut above the average but still contains all levels of ability.

TABLE AI

STUDENT COMPUTER EXPERIENCE

Group I	Special lectures only	80% of class
Group II	Math 173 or more	20% of class

Extremes: One student read the abridged manual only.

One student had industrial experience as a programmer.

PROBLEM-WORKING EXPERIENCE

No. of Problems Worked	Group I % of Group	Group II % of Group
0	65%	0
1–2	35%	0
2–5	0	0
5–10	0	50%
10–15	0	50%

3. The Computer Problem

The computer problem was assigned as a normal part of the course devoted to heat transfer. The problem is that of determining the temperature distribution in a two-dimensional semi-insulated solid (see 7. *Problem Assignment* and 8. *Instructor's Solution*). This particular problem was chosen because it is one of real engineering interest that cannot be solved analytically and, even more important, because it lends itself to machine solution. The problem not only serves as an exercise in the solution of heat transfer problems but also gives the student some insight into the potential of a computer.

Class lectures preceded the problem assignment. These lectures deal with the formulation of the heat equation and related boundary conditions as well as numerical techniques of solution. The problems associated with the numerical solution for the temperature distribution in solids were discussed in some detail and an iterative temperature correction technique was presented. The students were then assigned, as a home problem, the problem of determining by hand calculation the approximate temperature distribution in the semi-insulated solid (section 7) using a coarse ninepoint network. Their solutions were graded and returned.

The next phase of the problem was to modify their approach to the problem to make it amenable to machine solution. These modifications consisted of defining the method of solution explicitly, in particular the mechanism of iteration and the termination criteria. These were handled intuitively in the hand solution but must be defined explicitly for the

machine. This re-evaluation of the problem was presented in the form of a computer "Flow Sheet." The flow sheets were corrected and the various methods were discussed in class. The flow sheets consumed a major portion of the students' time and provoked quite a bit of interest.

The coding of the flow sheets into MAD language was then assigned and the students were then required to hand in punched cards which were sent to the computer for compilation and execution. Those unsuccessful were returned to the students for corrections and were resubmitted to the computer. A correct solution was required before the end of the semester (three weeks from the time the punched cards were first required and four weeks from the assignment of the original problem).

The students had the option of working in groups or alone. The maximum number in any one group was limited to three. Table AII shows how the students chose to group themselves.

4. Class Response

In an attempt to obtain objective information about time consumption and sources of difficulty a "problem evaluation sheet" was handed out with the problem assignment. It was emphasized in class that the information obtained from these evaluation sheets could not be traced back to its source and hence the students could be quite frank without fear of retaliation. This provides the major source of information for the statistics presented in this report.

The class is divided into two main groups according to computer experience. The first group has only the special lecture experience and constitutes 80% of the class. The second group is the more experienced, having Math 173 or more, and constitutes roughly the remaining 20% of the class. Table AI shows this division of programming experience.

TABLE AII

GROUP DISTRIBUTION

Number of Students per Group	% of Class So Grouped
1	18%
2	25%
3	57%

Total Number of Groups = 23.

TABLE AIII

STUDENT HOME TIME DISTRIBUTION

Group I, Special Lecture Group, 80% of Class

	Time in Hours				
	Theory	Flow Diagram	Coding	Punching	Corrections
Max	2.0	6.0	5.0	2.2	4.0
Average	1.0	3.0	2.5	1.4	1.0
Min	0.3	0.8	0.8	0.8	0.1

Total Average Time = 8.9 Hours

Group II, Math 173 or more, 20% of Class

	Time in Hours				
	Theory	Flow Diagram	Coding	Punching	Corrections
Max	0.3	6.0	1.5	1.0	0.3
Average	0.2	1.3	0.9	0.7	0.2
Min	0.1	0.3	0.5	0.5	0.1

Total Average Time = 3.3 Hours

The problem was divided into five main phases in an attempt to isolate the time-consuming and error-provoking sections of the problem. The phases are theory, flow diagramming, coding, card punching, and error correcting. Table AIII shows the amount of class time spent on each phase of the problem by the students. It is particularly interesting to compare the time spent by the experienced group to that spent by the inexperienced group. The major part of the students' time was spent on the flow diagramming and coding. The average student spent 8–9 hours out of class. The experienced man spent less and the inexperienced man much more.

IBM 704 computer time used by the class is reported as follows: Total time used by the 23 student groups and the instructor was 142 minutes. Each group required on an average of 4 trips to the computer to obtain a final solution with the total time consumed for each group averaging six minutes.

TABLE AIV

DISTRIBUTION OF REPORTED STUDENT ERRORS

Group I, Special Lecture, 80% of Class

	Theory	Flow Diagram	Coding	Punching
Average No. of Errors	0.7	1.0	4.0	6.0

Group II, Math 173 or more, 20% of Class

	Theory	Flow Diagram	Coding	Punching
Average No. of Errors	0.2	0.0	2.0	2.0

Table AIV shows the distribution of reported student "errors." The author hesitates to interpret these tables since a standard definition of an error was not presented to the class and hence the number of errors reported by the students is probably not on the same "scale."

5. Class Time Consumption

There has been some concern that the introduction of a computer problem into a course might consume time that could more profitably be used on other subjects. This may or may not be true. In this case the computer problem added to the content of the course.

Normally two to four home problems are assigned each week. These problems are discussed in the recitation sections. The students' solutions are graded and returned. The computer problem consumed one full hour of lecture and the equivalent of three hours of recitation. This eliminated 6 to 12 home problems from the course. In the period of time when the students were busy correcting their codes and resubmitting them to the computer regular class problems were again assigned and the class proceeded normally. I believe the computer experience was well worth the few problems sacrificed.

6. Instructor's Critique

This experience was quite educational both to the students and to the instructor. This critique could be titled "what the instructor learned."

The students are capable of more than originally anticipated if their interest is aroused. The home problems became somewhat of a necessary chore for the students and the computer problems presented a "change of pace" that stimulated the students' interest. The student enthusiasm could be sensed from the nature and number of questions asked during the recitation periods. I believe that the hours spent on the flow diagram and coding were willingly spent and those spent on the card punching far less willingly spent.

The relative simplicity of the MAD programming language and the availability of special lectures made this experiment possible. A minimum amount of time was needed for the student to become somewhat adept at the MAD language. Had the programming been required in a more complicated language I doubt if many of the students could have finished the problem.

The choice of the problem is quite important. Many problems that are "simple" physically, present some onerous programming difficulties. The problem should be worked by the instructor beforehand. This tends to eliminate those problems that the instructor "can't solve" and hence would eliminate some difficulties for the students.

In think it is a good idea to break the problem into several phases (i.e., flow chart, coding, etc.) allowing the student to become acclimated to the new way of thinking. Above all, plenty of time must be allowed for the final solution for the students are not just solving a problem but are learning a new approach to solving problems. This may take some time for the student to absorb.

The problem should be an integral part of the course and the instructor must be interested in the problem. Nothing dulls a student's enthusiasm as lack of enthusiasm on the instructor's part.

One danger exists that must be considered seriously. That is, they may believe the numbers received from the computer because of the fact that they came from the computer and for no other reason. The attitude may exist, "because the computer gives seven figures they are seven significant figures." This at-

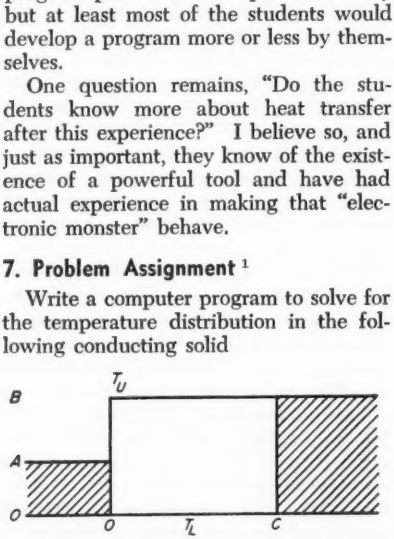
titude can be tempered by having a lecture on some of the problems of convergence and error propagation in the numerical solution of problems. This lecture should include some problems that cannot be worked on the computer. They should realize that there exists a field of mathematics concerned with the problems of "solvability" and they should be encouraged to develop a strong background in numerical analysis if they intend to use computers as tools.

It is a mistake to have the students work in large groups during the initial phases of the problem (flow sheets and coding). Several strong ones carry the ball and the weak ones fall behind. It may be better to have the students work alone on the initial phases and then select the better programs to be punched and run. Not all would actually have their program put on the computer this way but at least most of the students would develop a program more or less by themselves.

One question remains, "Do the students know more about heat transfer after this experience?" I believe so, and just as important, they know of the existence of a powerful tool and have had actual experience in making that "electronic monster" behave.

7. Problem Assignment [1]

Write a computer program to solve for the temperature distribution in the following conducting solid

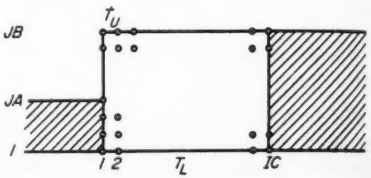


The upper surfaces are maintained at temperature T_U, the lower surface at T_L, and the sides are semi-insulated. The problem may be considered as two dimensional. The program should be capable of handling up to 400 mesh points and the computations should terminate either when a maximum number of iterations have been performed or when some degree of accuracy has been achieved, whichever comes first. You may want to prepare several sets of data for the computer to study, for example, the effect of mesh size on the solution. Hence the program should be able to handle arbitrary mesh size up to 400 points. The iterative correction method suggested in class is recommended.

[1] This section is the exact wording of the problem assigned to the students.

8. Instructor's Solution

Divide the solid into an array of mesh points.



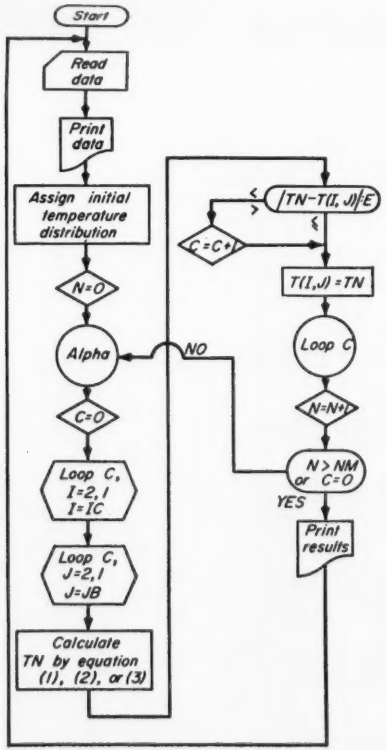
The first subscript refers to the horizontal direction and the second to the vertical. $T_{1,JB}$ is then the temperature at the upper left hand mesh point, for example.

The finite difference form of the heat equation and the boundary conditions relate the temperatures at the mesh points by the following relationships.

1) $T_{i,j} = (T_{i,j-1} + T_{i,j+1} + T_{i-1,j} + T_{i+1,j})/4$
   for $2 \leqslant i \leqslant IC-1$ and $2 \leqslant j \leqslant JB-1$
2) $T_{ij} = (T_{i,j+1} + T_{i,j-1} + 2T_{i-1,j})/4$
   for $2 \leqslant j \leqslant JB-1$ and $i = IC$
3) $T_{ij} = (T_{i,j-1} + T_{i,j+1} + 2T_{i+1,j})/4$
   for $i = 1$ and $2 \leqslant j < JA$
4 $T_{ij}) = T_U$
   for $1 \leqslant i \leqslant IC$ and $j = JB$
   or $i = 1$ and $JA \leqslant j \leqslant JB$
5) $T_{ij} = T_L$
   for $j = 1$.

An initial temperature distribution is assigned (in this case, linear) and it is then corrected by repetitive application of equations 1 through 5. The program is terminated when either the temperature at each point has been corrected N-max times or when the absolute value of successive temperature changes is less than E at every point. N-max and E are arbitrary constants given to the computer.

The instructor's flow diagram, program and solution follow.



* Detail not shown.
Flow Sheet for Instructor's Program

INSTRUCTOR'S
MAD LANGUAGE PROGRAM

```
 DALE F RUDD                    X18-N          001  001  001   1   009
 DALE F RUDD                    X18-N          001  001  001   1   009
*COMPILE MAD,EXECUTE
          R SCIENCE ENGINEERING  112 CLASS PROBLEM  HEAT TRANSFER
           DIMENSION  T(400,DIM),DIM(2)
           VECTOR VALUES DIM=2,1,20
READ       READ FORMAT DATA(1),JA,JB,IC,NM,TU,TL,E
           PRINT FORMAT DATA  ,JA,JB,IC,NM,TU,TL,E
           THROUGH LOOPA,FORJ=1,1,J.G.JB
           THROUGH LOOPA,FORI=1,1,I.G.IC
LOOPA      T(I,J)=TL+(TU-TL)*(J-1)/(JB-1)
           THROUGH LOOPB,FOR J=JA+1,J.G.JB
LOOPB      T(1,J)=TU
           N=0
ALPHA      C=0
           THROUGH LOOPC,FOR I=1,1,I.G.IC
           THROUGH LOOPC,FOR J=2,1,J.E.JB
           WHENEVER I.E.1.AND.J.L.JA
           TN=(T(I,J-1)+T(I,J+1)+2*T(I+1,J))/4.
           OR WHENEVER I.E.IC
           TN=(T(I,J+1)+T(I,J-1)+2*T(I-1,J))/4.
           OR WHENEVER I.E.1.AND. J.GE.JA
           TN=TU
           OTHERWISE
           TN=(T(I+1,J)+T(I-1,J)+T(I,J+1)+T(I,J-1))/4.
           END OF CONDITIONAL
           WHENEVER.ABS.(TN-T(I,J)).G.E,C=C+1
LOOPC      T(I,J)=TN
           N=N+1
           WHENEVER.NOT.(N.G.NM.OR.C.E.0),TRANSFER TO ALPHA
           PRINT FORMAT RESULT,N,C,T(1,1)...T (IC,JB)
           TRANSFER TO READ
           INTEGER I,J,JA,JB,IC,NM,C,N
           VECTOR VALUES DATA=$1H $,$4I4,3F10.2*$
           VECTOR VALUES RESULT=$3H N=I4,3H C=I4/(10F10.2)*$
           END OF PROGRAM
*DATA
  10  20  20  60     100.00     000.00       0.10
```

Format of Instructor's Results

```
JA    JB    IC    NMAX    TU    TL    E

"N=" XXX    "C=" XXXX

T(1,1)  T(1,2).............T(1,10)
T(1,11) T(1,12)............T(1,20)
T(2,1)  T(2,2).............T(2,10)
T(2,11) T(2,12)............T(2,20)
   .
   .
   .
T(20,1) T(20,2).............T(20,10)
T(20,11)  ..................T(20,20)
```

```
  10   20   20   60      100.00        0.00        0.10
N#  50 C=    0
```

0.00	7.19	14.55	22.20	30.31	39.08	48.88	60.39	75.45	100.00
100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
0.00	7.17	14.49	22.09	30.10	38.72	48.15	58.74	70.77	83.56
89.06	91.96	93.80	95.13	96.19	97.09	97.88	98.62	99.32	100.00
0.00	7.07	14.27	21.71	29.48	37.71	46.47	55.78	65.44	74.52
80.78	85.07	88.18	90.59	92.58	94.30	95.85	97.29	98.66	100.00
0.00	6.91	13.94	21.14	28.60	36.35	44.40	52.67	60.86	68.42
74.59	79.46	83.35	86.56	89.31	91.75	93.97	96.05	98.05	100.00
0.00	6.72	13.53	20.47	27.59	34.88	42.32	49.80	57.10	63.89
69.86	74.96	79.31	83.09	86.44	89.47	92.28	94.93	97.49	100.00
0.00	6.52	13.10	19.78	26.56	33.45	40.40	47.30	54.02	60.36
66.15	71.35	75.99	80.17	83.97	87.49	90.79	93.94	97.00	100.00
0.00	6.32	12.68	19.10	25.60	32.15	38.70	45.19	51.52	57.56
63.22	68.46	73.29	77.75	81.90	85.80	89.51	93.09	96.57	100.00
0.00	6.13	12.29	18.49	24.73	31.00	37.25	43.44	49.49	55.32
60.89	66.14	71.09	75.76	80.18	84.39	88.44	92.36	96.21	100.00
0.00	5.96	11.94	17.95	23.98	30.02	36.04	42.00	47.85	53.54
59.03	64.29	69.33	74.15	78.77	83.23	87.54	91.76	95.90	100.00
0.00	5.81	11.64	17.49	23.35	29.21	35.05	40.84	46.54	52.12
57.55	62.82	67.92	72.85	77.63	82.28	86.81	91.26	95.65	100.00
0.00	5.69	11.39	17.11	22.83	28.55	34.25	39.90	45.49	50.99
56.39	61.66	66.80	71.82	76.72	81.52	86.22	90.86	95.45	100.00
0.00	5.59	11.19	16.80	22.41	28.02	33.61	39.16	44.67	50.11
55.48	60.75	65.93	71.01	76.00	80.91	85.75	90.54	95.28	100.00
0.00	5.51	11.03	16.55	22.08	27.60	33.10	38.59	44.03	49.43
54.77	60.04	65.24	70.37	75.44	80.44	85.38	90.28	95.15	100.00
0.00	5.45	10.90	16.36	21.82	27.27	32.72	38.14	43.54	48.91
54.23	59.50	64.72	69.89	75.00	80.07	85.10	90.09	95.05	100.00
0.00	5.40	10.80	16.21	21.62	27.03	32.42	37.81	43.17	48.51
53.82	59.09	64.32	69.52	74.67	79.79	84.88	89.94	94.98	100.00
0.00	5.36	10.73	16.10	21.47	26.84	32.21	37.56	42.90	48.22
53.52	58.79	64.03	69.24	74.43	79.58	84.71	89.82	94.92	100.00
0.00	5.34	10.68	16.02	21.37	26.71	32.05	37.38	42.71	48.01
53.30	58.57	63.82	69.05	74.25	79.43	84.60	89.74	94.88	100.00
0.00	5.32	10.65	15.97	21.30	26.63	31.95	37.27	42.58	47.88
53.16	58.43	63.69	68.92	74.14	79.34	84.52	89.69	94.85	100.00
0.00	5.31	10.63	15.95	21.26	26.58	31.90	37.21	42.51	47.80
53.09	58.36	63.61	68.85	74.07	79.28	84.48	89.66	94.83	100.00
0.00	5.31	10.62	15.94	21.26	26.57	31.88	37.19	42.49	47.79
53.07	58.34	63.59	68.83	74.06	79.27	84.47	89.65	94.83	100.00

9. Student Solutions

Two student solutions are given here which, in the instructor's opinion, are superior to his own. The first is by Lee H. Frame, and the second is by John Herman.

FRAME'S *MAD* LANGUAGE PROGRAM

```
          R LEE H. FRAME      SE. 112  HEAT TRANSFER PROBLEM
          DIMENSION  T(400,DIM)
          READ FORMAT INPUT, IC, JA, JB, NM, TU, TL, E
          PRINT FORMAT TITLE, TU, TL, JA, JB, IC, NM, E
          THROUGH BARB, FOR I=1, 1, I .G. IC
          THROUGH BARB, FOR J=1 ,1, J .G. JB
BARB      T(I,J)=5*(J-1)
          N=0
SANDIE    C=0
          THROUGH ANN, FOR I=1, 1, I .G. IC
          THROUGH ANN, FOR J=1, 1, J .G. JB
          WHENEVER J.E.1
          TN=TL
          OR WHENEVER  J.E.JB
          TN=TU
          OR WHENEVER  I.E.1 .AND. J.GE. JA
          TN=TU
          OR WHENEVER I.E.1 .AND. J.G.1 .AND. J.L.JA
          TN=(T(1,J+1)+T(I,J-1)+2*T(2,J))/4
          OR WHENEVER I.E.IC .AND. J.G.1 .AND. J.L.JB
          TN=(T(IC,J+1)+T(IC,J-1)+2*T(IC-1,J))/4
          OR WHENEVER  I.G.1 .AND. J.G.1 .AND. J.L.JB .AND. I.L.IC
          TN=(T(I,J+1)+T(I,J-1)+T(I+1,J)+T(I-1,J))/4
          END OF CONDITION
          WHENEVER .ABS. (TN-T(I,J)).G.E. C=C+1
ANN       T(I,J)=TN
          N=N+1
          WHENEVER N.L.NM .AND. C.G.0, TRANSFER TO SANDIE
          PRINT FORMAT RESULT , C, N, T(1,1)...T(IC,JB)
          INTEGER  I,J,JA,JB,IC,NM,C,N
          VECTOR VALUES DIM =2,1,20
          VECTOR VALUES INPUT=$4I4, 3F10.2*$
          VECTOR VALUES TITLE=$1H1  30H HEAT FLOW IN CONDUCTING BLOCK
         1 /// 4H TU=F6.2 / 4H TL=F6.2 / 4H JA=I4 / 4H JB=I4 / 4H IC=I4
         2 / 4H NM=I4 / 3H E=F4.2*$
          VECTOR VALUES RESULT=$3H C=I4 / 3H N=I3 /// (20F6.2)*$
          END OF PROGRAM
```

Format of Frame's Output

```
"HEAT FLOW IN CONDUCTING BLOCK"
"TU="  XXX
"TL="  XXXX
"JA="  XXXX
"JB="  XXXX
"IC="  XXXX
"NM="  XXXX
"E ="  XXXX
"C ="  XXXXX
"N ="  XXXX

T(1,1)   T(1,2) . . . . . .T(1,19)  T(1,20)
T(2,1)   T(2,2) . . . . . .T(2,19)  T(2,20)
.
T(20,1)  T(20,2). . . . . .T(20,19) T(20,20)
```

HEAT FLOW IN CONDUCTING BLOCK

TU=100.00
TL= 0.00
JA= 10
JB= 20
IC= 20
NM= 40
E#0.10
C# 98
N# 40

0.00	6.68	13.56	20.81	28.62	37.23	47.03	58.75	74.32	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
0.00	6.66	13.51	20.71	28.43	36.87	46.28	57.01	69.37	82.64	88.32	91.33	93.24	94.64	95.76	96.74	97.62	98.44	99.23	100.00
0.00	6.57	13.30	20.34	27.81	35.83	44.52	53.89	63.72	73.03	79.46	83.88	87.11	89.65	91.77	93.64	95.34	96.95	98.49	100.00
0.00	6.42	12.98	19.79	26.92	34.44	42.36	50.60	58.86	66.54	72.83	77.83	81.86	85.23	88.16	90.80	93.24	95.57	97.81	100.00
0.00	6.24	12.59	19.13	25.90	32.94	40.20	47.59	54.87	61.71	67.76	72.98	77.48	81.44	85.00	88.29	91.37	94.32	97.19	100.00
0.00	6.05	12.18	18.45	24.89	31.49	38.22	44.99	51.64	57.98	63.82	69.12	73.91	78.28	82.32	86.12	89.74	93.24	96.64	100.00
0.00	5.86	11.78	17.81	23.95	30.19	36.51	42.83	49.05	55.05	60.73	66.06	71.02	75.68	80.09	84.30	88.36	92.31	96.18	100.00
0.00	5.69	11.42	17.23	23.12	29.07	35.07	41.06	46.98	52.75	58.31	63.63	68.72	73.59	78.27	82.80	87.21	91.53	95.79	100.00
0.00	5.53	11.11	16.73	22.41	28.14	33.90	39.64	45.24	50.94	56.42	61.74	66.90	71.91	76.80	81.58	86.27	90.90	95.47	100.00
0.00	5.41	10.85	16.32	21.84	27.39	32.96	38.52	44.06	49.54	54.95	60.26	65.47	70.60	75.64	80.61	85.52	90.38	95.21	100.00
0.00	5.31	10.64	15.99	21.38	26.79	32.22	37.66	43.08	48.47	53.82	59.12	64.37	69.57	74.73	79.84	84.93	89.98	95.00	100.00
0.00	5.23	10.47	15.74	21.02	26.33	31.66	36.99	42.32	47.65	52.96	58.26	63.53	68.79	74.03	79.25	84.47	89.66	94.84	100.00
0.00	5.16	10.34	15.54	20.75	25.98	31.23	36.49	41.76	47.04	52.32	57.61	62.90	68.20	73.50	78.81	84.11	89.42	94.72	100.00
0.00	5.12	10.25	15.39	20.55	25.72	30.91	36.12	41.34	46.59	51.85	57.13	62.43	67.76	73.11	78.47	83.85	89.24	94.62	100.00
0.00	5.08	10.18	15.28	20.40	25.53	30.68	35.85	41.04	46.26	51.50	56.78	62.09	67.44	72.82	78.23	83.66	89.10	94.55	100.00
0.00	5.06	10.13	15.20	20.29	25.40	30.52	35.66	40.83	46.03	51.26	56.54	61.85	67.21	72.61	78.05	83.52	89.01	94.51	100.00
0.00	5.04	10.09	15.15	20.22	25.30	30.40	35.53	40.68	45.87	51.10	56.37	61.69	67.06	72.48	77.94	83.43	88.94	94.47	100.00
0.00	5.03	10.07	15.12	20.17	25.25	30.34	35.45	40.59	45.77	51.00	56.27	61.59	66.97	72.39	77.86	83.37	88.90	94.45	100.00
0.00	5.03	10.06	15.10	20.15	25.22	30.30	35.41	40.55	45.73	50.95	56.22	61.55	66.92	72.35	77.83	83.35	88.89	94.44	100.00
0.00	5.03	10.06	15.10	20.15	25.21	30.30	35.41	40.55	45.73	50.95	56.22	61.55	66.93	72.36	77.83	83.35	88.89	94.44	100.00

ALPH
BETA
A1
A2
A3
A7
PHI
A4
A5
GAMM
A6

HERMAN'S *MAD* LANGUAGE PROGRAM

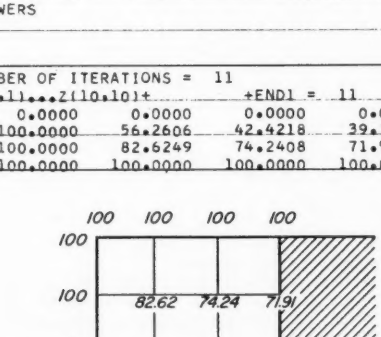
```
            DIMENSION  Z(400,V),V(5)
            VECTOR VALUES V    = 2,1,20
ALPHA       READ FORMAT CARD1,TU,TL,EE
            READ FORMAT CARD2,JA,JB,IC,NM
            PRINT FORMAT TITLE,TU,TL,EE
            PRINT FORMAT DATA,JA,JB,IC,NM
            X=TU/(JB-1)
            Y=X
            THROUGH A1,FOR J=2,1,J.E.JB+1
            THROUGH A2, FOR I=1,1,I.E.IC+1
A2          Z(J,I) = X
A1          X = X+Y
            END1 = 0
BETA        END2 = 0
            THROUGH A7, FOR J=1,1,J.E.JB+1
            THROUGH A3, FOR I=1,1,I.E.IC+1
            WHENEVER 1.L.I.AND.I.L.IC.AND.1.L.J.AND.J.L.JB
            R=(Z(J+1,I)+Z(J-1,I)+Z(J,I+1)+Z(J,I-1))/4.
            OR WHENEVER J.E.1
            R = TL
            OR WHENEVER (I.E.1.AND.J.GE.JA).OR.J.E.JB
            R = TU
            OR WHENEVER I.E.1.AND.J.L.JA
            R=(Z(J-1,I)+Z(J+1,I)+2*Z(J,I+1))/4.
            OR WHENEVER I.E.IC
            R=(Z(J-1,I)+Z(J+1,I)+2*Z(J,I-1))/4.
            END OF CONDITIONAL
            WHENEVER .ABS.(Z(J,I)-R).GE.EE;END2=END2+1
A3          Z(J,I)=R
A7          CONTINUE
            END1=END1+1
            WHENEVER END1.GE.NM.OR.END2.E.0,TRANSFER TO PHI
            TRANSFER TO BETA
PHI         PRINT FORMAT ANSWER,END1
            WHENEVER IC.G.10,TRANSFER TO GAMMA
A4          PRINT FORMAT R1,END1
            THROUGH A5, FOR J=1,1,J.E.JB+1
A5          PRINT FORMAT RESULT,Z(J,1),...,Z(J,IC)
            TRANSFER TO ALPHA
GAMMA       PRINT FORMAT R2,END1
            THROUGH A6, FOR J=1,1,J.E.JB+1
A6          PRINT FORMAT RESULT, Z(J,11),...,Z(J,IC)
            IC=10
            TRANSFER TO A4
            INTEGER I,J,END1,END2,JA,JB,IC,NM
            VECTOR VALUES CARD1=$3E10.6*$
            VECTOR VALUES CARD2=$4I4*$
            VECTOR VALUES TITLE=$41H1SOLUTION OF SE 112 PROBLEM BY RELAXA
           1TION/5HOTU =F10.2,S1,4HTL =F10.2,S1,4HEE =F10.6*$
            VECTOR VALUES DATA=$5HOJA =I4,S1,4HJB =I4,S1,4HIC =I4,S1,
           14HNM =I4*$
            VECTOR VALUES RESULT=$1H ,10F11.4*$
            VECTOR VALUES ANSWER=$8H ANSWERS///23HONUMBER OF ITERATIONS =
           1I4*$
            VECTOR VALUES R1=$18H Z(1,1),...,Z(10,10),10H+          ,7H+END1
           1 =I4*$
            VECTOR VALUES R2=$20H Z(11,11),...,Z(20,20),10H+          ,7H+EN
           1D1 =I4*$
            END OF PROGRAM
```

Format of Herman's Output

```
"SOLUTION OF SE112 PROBLEM BY RELAXATION"
"TU= XXXXX"  "TL="  XXXX      "EE= XXX"
"JA= XXX"    "JB="  XXX       "NM=" XXXX

"ANSWERS"
"NUMBER OF ITERATIONS="  XXXX
"Z(11,11)....Z(20,20) +      + END1 =" XX
T(11,1)    T(12,1)    T(13,1) . . . . . T(20,1)
T(11,2)    T(12,2) . . . . . .T(20,2)
    .
    .
    .
T(11,20)   T(12,20). . . . . .T(20,20)
"Z(1,1).....Z(10,10) +      + END1 =" XX

T(1,1)     T(2,1). . . . . .T(10,1)
T(1,2)     T(2,2). . . . . .T(10,2)
    .
    .
    .
T(1,20)    T(2,20). . . . . T(10,20)
```

Case A
Coarse Mesh

```
SOLUTION OF SE 112 PROBLEM BY RELAXATION
TU =    100.00 TL =      0.00 EE =  0.005000

JA =   2 JB =   4 IC =   4 NM = 100
ANSWERS

NUMBER OF ITERATIONS =  11
Z%1,11)...Z(10,10)+          +END1 =  11
     0.0000      0.0000      0.0000      0.0000
   100.0000     56.2606     42.4218     39.1900
   100.0000     82.6249     74.2408     71.9179
   100.0000    100.0000    100.0000    100.0000
```



Fine Mesh

SOLUTION OF SE 112 PROBLEM BY RELAXATION

TU = 100.00 TL = 0.00 EE = 0.005000

CASE II
FINE MESH

SOLUTION OF SE 112 PROBLEM BY RELAXATION

TU = 100.00 TL = 0.00 EE = 0.005000

JA = 10 JB = 20 IC = 20 NM = 100

ANSWERS

NUMBER OF ITERATIONS = 100

Z(1,11)...Z(20,20)+ +END1 = 100

0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6.1096	5.9708	5.8531	5.7553	5.6759	5.6134	5.5666	5.5344	5.5161	5.5113
12.2118	11.9346	11.6999	11.5051	11.3472	11.2230	11.1300	11.0662	11.0299	11.0204
18.2930	17.8783	17.5286	17.2391	17.0047	16.8208	16.6833	16.5888	16.5352	16.5210
24.3366	23.7874	23.3264	22.9461	22.6390	22.3985	22.2188	22.0956	22.0256	22.0070
30.3233	29.6453	29.0794	28.6144	28.2401	27.9475	27.7292	27.5797	27.4947	27.4721
36.2304	35.4338	34.7727	34.2319	33.7978	33.4593	33.2072	33.0346	32.9366	32.9103
42.0331	41.1336	40.3912	39.7863	39.3024	38.9258	38.6458	38.4542	38.3455	38.3162
47.7064	46.7258	45.9205	45.2665	44.7448	44.3395	44.0387	43.8330	43.7162	43.6847
53.2276	52.1938	51.3477	50.6627	50.1172	49.6943	49.3806	49.1663	49.0446	49.0116
58.5795	57.5248	56.6636	55.9675	55.4141	54.9854	54.6677	54.4508	54.3275	54.2940
63.7526	62.7117	61.8625	61.1767	60.6318	60.2101	59.8976	59.6843	59.5631	59.5300
68.7460	67.7537	66.9437	66.2896	65.7700	65.3678	65.0699	64.8665	64.7509	64.7192
73.5676	72.6560	71.9111	71.3091	70.8307	70.4603	70.1859	69.9985	69.8920	69.8627
78.2319	77.4296	76.7729	76.2415	75.8189	75.4915	75.2490	75.0833	74.9891	74.9631
82.7592	82.0898	81.5408	81.0961	80.7420	80.4677	80.2643	80.1253	80.0462	80.0244
87.1731	86.6552	86.2298	85.8847	85.6097	85.3965	85.2384	85.1303	85.0688	85.0518
91.4995	91.1469	90.8568	90.6212	90.4334	90.2876	90.1795	90.1056	90.0635	90.0518
95.7658	95.5873	95.4403	95.3209	95.2256	95.1516	95.0967	95.0592	95.0378	95.0318
100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

Z(1,1)...Z(10,10)+ +END1 = 100

0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7.8373	7.8006	7.6913	7.5249	7.3207	7.0979	6.8719	6.6543	6.4523	6.2701
15.7685	15.6890	15.4552	15.1028	14.6758	14.2145	13.7513	13.3085	12.9001	12.5336
23.8929	23.7559	23.3617	22.7801	22.0898	21.3583	20.6353	19.9532	19.3307	18.7766
32.3362	32.1110	31.4868	30.5982	29.5777	28.5266	27.5116	26.5716	25.7259	24.9811
41.2821	40.9007	39.9129	38.5857	37.1348	35.6983	34.3531	33.1359	32.0599	31.1247
51.0461	50.3343	48.7173	46.7379	44.7202	42.8231	41.1117	39.6047	38.2984	37.1793
62.2867	60.7092	57.9237	54.9705	52.2303	49.8091	47.7145	45.9221	44.3990	43.1127
76.7271	72.3243	67.3347	63.0320	59.4668	56.5170	54.0656	52.0215	50.3148	48.8910
100.0000	84.5514	76.0921	70.3957	66.1325	62.7744	60.0599	57.8356	56.0005	54.4825
100.0000	89.8100	82.1163	76.3630	71.9355	68.4348	65.6134	63.3119	61.4212	59.8633
100.0000	92.5898	86.2268	81.0385	76.8514	73.4598	70.6943	68.4263	66.5594	65.0203
100.0000	94.3377	89.1862	84.7435	81.0079	77.8993	75.3214	73.1856	71.4168	69.9536
100.0000	95.5881	91.4576	87.7685	84.5699	81.8446	79.5461	77.6195	76.0115	74.6745
100.0000	96.5682	93.3054	90.3265	87.6865	85.3949	83.4335	81.7713	80.3729	79.2037
100.0000	97.3889	94.8840	92.5650	90.4784	88.6416	87.0509	85.6900	84.5370	83.5678
100.0000	98.1106	96.2884	94.5863	93.0391	91.6634	90.4613	89.4254	88.5425	87.7971
100.0000	98.7706	97.5811	96.4639	95.4417	94.5267	93.7223	93.0254	92.4289	91.9236
100.0000	99.3940	98.8066	98.2533	97.7452	97.2886	96.8858	96.5357	96.2353	95.9802
100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

Understanding the Elements of Effective Teaching

H. T. MORSE

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Anyone planning to build a dog house or take a trip would surely be considered improvident, if not downright silly, if he did not construct a plan for his enterprise. Yet it is amazing how many young college instructors enter upon their first teaching assignment, and may perhaps continue year after busy year, without constructing any cogent plans for what they hope to accomplish in the classroom.

In preparing any plan, there are certain major reference points or land marks to be observed in charting the course of daily classroom activities. These are, in descending order of magnitude and increasing order of specificity, the context of higher education as a whole, the major purpose of the college or unit in which the instruction takes place, the purposes of the course being taught, and the learnings to be achieved in the specific class session. To educate is to change behavior. Therefore, any effective plan for educating should be couched in terms of those behaviors which one wishes to condition or to change.

Learning to teach and, in the larger sense, becoming an engineering educator, are processes about which we really know very little. They continually take place, they are very important, and they will soon become urgent. After much thoughtful study, the Committee on the Development of Engineering Faculties of ASEE organized the Cleveland Conference of 19–21 November, 1959, to bring together a small group who could identify and assemble the resources in our own and other fields, including formal education, that can best aid this process of learning to become a teacher and educator. This paper is one of the series originating from that Cleveland Conference.

All teachers—not only those in engineering programs—should be interested in maximum efficiency. Therefore, they ought to make optimum use of those minutes which are at their command at each class session, and in order to do so they should construct a list of purposes to be attained and a plan for attaining these purposes or objectives. And the preparation of a list of such major learning outcomes provides also a framework for subsequent evaluation of student achievement. For evaluation, to be valid and proper, should be closely geared to the objectives of instruction.

Earlier statements of purposes or plans almost always involved "mastery of facts," and I suspect that not only in engineering but in any other field, instructors who are embarking upon this exciting journey of college teaching think primarily in terms of getting the student to know the facts. This is, in a way, a concept of mental discipline. You may remember that when Alice and the White Rabbit and their companions were engulfed in the pool of tears at the bottom of the well they sought means to dry themselves out. Alice suggested that someone read passages from Gibbon's *History of the Decline and Fall of the Roman Empire*, because, said she, that is the driest thing I know. There are undeniably other desirable outcomes of instruction, and I am sure that teachers of engineering subjects would be among the first to say that knowledge of facts alone is not sufficient. We must be concerned also with the understanding of basic principles, with ability to analyze and to generalize, ability to apply knowledge to solving problems, and so on. These were long considered as by-products or corollaries of factual learning. But numerous investigations have indicated that they do not auto-

matically accrue to the individual who knows the facts.

In the last few years some rather interesting shifts or new dimensions are being probed in liberal arts instruction, and, I presume, these would apply also in engineering institutions and technical institutes. One of these is critical thinking, which had long been accepted rather glibly as a desirable aim of instruction, but deplorably little had been done to develop and to evaluate this kind of learning. It was my privilege a number of years ago to participate in the American Council on Education sponsored study of the evaluation of the outcomes of general education. There were six intercollege committees representing nineteen institutions, and of the six committees representing fields such as the humanities, the social sciences, the sciences, communication, etc., four of these committees, in independent deliberations, came out with the assertion that one of the most important elements in their field was the ability to think critically.

Another trend in recent years has been toward the integration of learning. We have heard a great deal in higher education and elsewhere about fragmentation, and therefore we are interested in pulling the fragments together into meaningful wholes, because only as learning can be articulated, only as it can be arranged into meaningful patterns, can there be the desired changes in behavior.

A third outcome which has received much attention lately is that of values. A sputnik in the educational world was launched recently by Philip E. Jacob, called *Changing Values in College.* I quote in Jacob's own words the following from a later report: "A study of what happens to the values of American students of today shows that their college experience barely touches their standards of behavior, quality of judgment, sense of social responsibility, perspicacity of understanding, and guiding beliefs."[1] Could there be any more damning indictment of what we are attempting to do in higher education and indeed in all education? There have been a number of follow-up investigations, and it is hoped that this particular problem will receive sustained and effective consideration.

Another new development is that of creativity. I was interested in hearing what Professor William LeBold had to say about the creativity unit in their orientation of new instructors at Purdue University. I notice also that some of the publications dealing with engineering talk about creative engineering and creative teaching in engineering programs.

Still another concept which we are coming to grasp, and, I hope, to accept, is the understanding of the student as a total being. Now, much ink has been shed to debate the proposition as to whether we are teaching content or whether we are teaching development of young people. There need be no conflict between these two at all because, as every good teacher surely knows, we are trying to develop individuals as well as to teach them to learn content. One way to get around this apparent dilemma is to construct a two-dimensional chart. Along one side of the chart we may enter the items or topics of subject matter content which we desire the students to learn. Along the other axis of this chart, and correlated with each topical entry, we may list the desirable learnings which we wish to encourage beyond factual content, such as: understanding of important facts and principles, knowing how to get additional information, ability to interpret data, ability to apply principles, ability to report results of study, ability to apply learning to new situations. This list could be extended at some length in terms of the field taught. To put this in capsule form, I would say that the successful teacher is the one whose students attain most satisfactorily these dual purposes of instruction.

If we are to ask ourselves what are the characteristics of the effective classroom teacher, I would say first and foremost, without fear of any contradiction, that it is knowledge of his subject matter field. Last spring at the Association meeting, Dean Harold Hazen is reported to have said, "More than ever the life of the pro-

[1] Philip E. Jacob, "Does Higher Education Influence Student Values?" *Spotlight on the College Student.* Washington, D. C.: American Council on Education, 1959, p. 3.

fessor must be the life of a student." [2] This is assuredly true in all fields. In an article in a recent issue of the JOURNAL OF ENGINEERING EDUCATION, Richard Sutton made this statement, among others, in a list of very practical suggestions to beginning teachers: "Know your subject thoroughly. Take plenty of time to prepare, no matter how often you have covered the subject before." [3] And again in a follow-up study of the characteristics of engineering teachers, the first point in this description of the desirable teacher is, "A thorough knowledge of and interest in his subject. Engineering alumni overwhelmingly stated that the instructor in scientific and technical subjects must have this trait." [4]

I have heard my colleagues say sometimes that if a man knows his subject, he can teach it well. This comfortable assurance has been contradicted by many studies and analyses of teaching. There is no automatic transfer to the ability to put a subject across, because we are concerned with a different element in the latter factor from pure knowledge of the subject itself. It is my belief also that the teacher ought to have an interest and a competence not only in his own field of specialization, but should have a sound general education as well. I should not like to leave this to chance or casual accomplishment. Instead I should like to see included in the engineering program itself, as is actually happening in many places—and I think that M.I.T. was one of the first—training in the social sciences and the humanities correlated with that in the engineering specialties.

Still another characteristic which is highly desirable in the successful teacher is that of understanding the learning process. One of the things that the beginning teacher frequently has most difficulty in grasping is that students may appear to know things without actually knowing them. This is more fundamental than that look of rapt attention which hides the fact that the individual student may be building castles in Spain or wool gathering thousands of miles away—I refer to the sort of thing we call verbalization. The psychologist William James gives a prime example. He tells the story of a visitor to a grade school class. The teacher informed the visitor that the children had been studying the earth, sort of an elementary geology. The visitor said she would welcome the opportunity to put a question. So she said, "Well now children, you've been studying about the earth and its composition. I would like to ask you, if you were to dig a hole miles deep, way down into the earth, at the bottom of that hole would it be warmer than it is on the surface, or would it be colder?" The children were puzzled. None seemed to know the answer. The questioner was visibly distressed. Finally the teacher said, "Excuse me, I don't think you put the question in quite the right way. Let me ask them." So the teacher said, "Children, in what state is the interior of the globe?" And the chorus of replies came, "The interior of the globe is in a state of igneous fusion!" One could readily find illustrations of this kind to let us know that this can and does happen even at the college level. In this connection I like the comment that one of Sarah Blanding's students made one time when, after many efforts by Miss Blanding to get the student to see the point of developing learning and an attitude towards it in youngsters, the girl finally said, "Oh, Miss Blanding, now I see what you mean. First you kindle a spark, then you water it carefully."

Studies which have been made of the learning and teaching process are for the most part on the "Never-to-be-read" list of college instructors. That is to say, it is deplorable, but true, nevertheless, that very few college teachers are interested in the numerous studies available about the teaching-learning process. The President's Commission on Higher Education, which made its report in 1947, declared in this connection that the only profession for which there is no systematic

[2] JOURNAL OF ENGINEERING EDUCATION, Oct. 1959, p. 15.

[3] Richard M. Sutton, "Reflections on Teaching I have Seen," JOURNAL OF ENGINEERING EDUCATION, June 1959, p. 959.

[4] Herman A. Estrin, "Engineering Alumni Describe Their Teachers," *Improving College and University Teaching*, Autumn 1959, p. 114.

training in the activities in which the practitioner will engage is that of college teaching.

Another characteristic of the successful teacher is the use of a variety of instructional aids. It is hardly necessary for me to detail these here—such things as audio-visual aids, slides, models, movies, tapes, film strips, recordings—and to our young instructors I say, do not forget the most fundamental and simple of instructional aids, the blackboard. It is amazing how often some of them will conduct a class as if the blackboard did not even exist.

An outstanding hallmark of the good classroom teacher is the use of imagination and resourcefulness in presenting learning situations. College teachers often think in terms of the content to be covered, as I have stated before, rather than the method of presentation to be used. This is quite different from the virtuoso in the field of music or the other arts. The great Paderewski was once asked by an admirer why he bothered to practice every day. Said Paderewski, "If I miss one day's practice, I know it. If I miss two days' practice, the critics know it. If I miss three days' practice, the audience knows it." College instructors, however, give surprisingly little time to thinking about the way in which they are going to make the content of whatever they are teaching meaningful and effective.

There are a number of illustrations I may give of what I would call "the use of imagination and resourcefulness." I read at one time, for example, of a professor of sociology in a small college who was conducting student readings and discussions and classwork on the influence of folkways and customs in molding behavior and enforcing conformity. This professor decided he would teach these youngsters a lesson they would not readily forget. Therefore, he said to the class, "Let us have a conspiracy. No one will know this except you and me. For one week wear your best clothes every single day, and keep track of the comments that are made." So, for a week, these young people wore their best clothes, instead of the customary sweaters, slacks, skirts, and bobby sox. I leave it to your imagination to guess what their roommates and their friends said. These young people surely had their academic learning powerfully reinforced, to realize that one of our most influential sociological forces is custom.

We had in the General College at the University of Minnesota an instructor in biology, a young man who taught a unit on genetics which he timed to his family cat. It so happened that this was a female cat, and anyone who has had experience with female cats knows what happens when they are allowed to roam indiscriminately at night. And so, when the time came for the discussion on genetics, Ed would have a basket of kittens that were by this time five or six weeks old. He brought this to the class, so that they could have living illustrations of the inheritance of dominant and recessive characteristics—the long hair, the short hair, the eye color, and whatever other characteristics cats have which may be included in such a lesson. This lesson was, I am sure, because of the particular device he used, something that the young people did not soon forget. (But, of course, he had an ulterior motive, too. He had run out of friends, in a certain sense, by that time, so when the lesson was over, he would say to this large class, "Well now, would any of you like to have one of these kittens?" And immediately there would be a waving of hands, and this was a most successful and effective way of teaching a lesson and of getting rid of the produce of the family cat at the same time.)

The thing that is essential, it seems to me, is to create in the individual teacher a desire to improve his teaching. We have used student rating forms for this purpose at the University of Minnesota. Space does not permit a description of how these are administered and used, but just a reading of some items is, I think, good therapy, "How clearly does your instructor present his subject matter?: (a) Among the best instructors in clarity of presentation, (b) clearer than most instructors, (c) about average in clarity of presentation, (d) less clear than most instructors, (e) among the poorest

instructors in clarity of presentation." Each one of these items is graduated in five categories: "How well does he seem to be prepared for the class meeting?"—a, b, c, d, e. "How much original thinking is demanded of you?" "How free is he from annoying personal peculiarities and mannerisms?" "Would you recommend this course to a good friend whose interests are like yours?" "How would you rate your instructor in general, all-around teaching ability?"

In conclusion, then, I would say that the conditions under which effective teaching may thrive, by and large, are three. First of all, understanding of all concerned that teaching and learning are complex processes. They depend on many factors, among which are the personality and background of the instructor, the type of the material to be taught and learned, the level of student ability, the motivation of the students, the physical conditions of the classroom, and the morale of the faculty member.

Secondly, the demonstration of a sincere interest in good teaching by deans and department heads. I noted in the JOURNAL OF ENGINEERING EDUCATION for October, 1959, the presidential address by Dean Alexander of Northeastern University, which underscores this point, as follows: "The identification and public recognition of good teaching in the classroom, however, is much more difficult. Consequently, in too many institutions the administration becomes submerged in the detail of educational supervision, and high quality and imaginative teaching receives so little recognition that the faculty become confused and wonder whether or not the administration really cares about top level performance in the classroom. Well thought out programs of publicly recognizing these virtuosos of the classroom would pay great dividends in faculty morale and in increased classroom effectiveness." [5] The activities of your Committee on the Development of Engineering Faculties are to be commended highly, indeed, because they are concerned with the more effective preparation of young engineering teachers to do the best job they can. And the teachers are our seed corn. If they are not good, the product of their teaching will be less good.

And finally, as those in administrative positions fully realize, if we really mean that we are interested in good teaching, we must give tangible evidence of that interest. We must give increases in salary and promotion in rank to those whom we know to be good classroom teachers. They should not be too easily passed over, with the laurels going to the man with the longest bibliography. And so I am heartened to see this interest in improved teaching on the part of the members of this committee of your association. It is encouraging indeed to note the illustrations given of engineering faculty development programs and devices in the committee report prepared and written by Harold A. Foecke. I hope that this effort may be part of a chain reaction, and that the good work which is being done by the committee and the excellent illustrations of improved practices in engineering programs described will bear fruit in upgrading instructional practices in engineering education as a whole.

[5] W. T. Alexander, "Engineering Education, Experience, and Expectation," JOURNAL OF ENGINEERING EDUCATION. Oct. 1959, p. 12.

TV COURSE FOR INDUSTRY

An experiment in radio-TV education is being conducted at a Milwaukee plant of AC Spark Plug, the Electronics Division of General Motors. A special closed circuit TV line is carrying a class in network theory from the University of Wisconsin campus in Madison to the AC Spark Plug plant in suburban Milwaukee, a distance of about 80 miles. Also joining in the experiment is the University of Wisconsin's branch in downtown Milwaukee, making a three-way network out the experiment.

Class sessions originate in Madison. Through the use of a three-way audio system, students in any of the three class areas may communicate with the professors in Madison. All they have to do is pick up a telephone handset and talk into it. The professor as well as the other classes can hear and participate in the conversation.

What Industry Is Doing for Continued Education of Engineers

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Competition has always been the keyword in United States industry. The way my product stacks up with yours in the marketplace has been the motive power for a large part of this country's progress. It has been our pride—and, I think, a justifiable pride—that we have been able to offer the nation and the world a continuously growing number of better and better products in almost infinite variety.

But in our preoccupation with products, it is now quite apparent that we failed fully to gauge the tremendous technological momentum that we were building up in producing them.

I have been interested, in this connection, to read about the current dilemma in the aircraft industry. The switch to jets by the manufacturers and the commercial airlines was certainly in the best tradition of our competitive economy. But the vast increase in speed and pay load of the new planes made it not only possible but good business logic for the lines to increase the number of flights. Result: a disconcerting number of empty seats.

The aircraft industry will solve this problem, of course, even though it is already talking about the supersonic commerical planes that will make obsolete present jets just as they, themselves, are displacing piston craft.

Address delivered to The American Society for Engineering Education, 1960 Annual Meeting, Purdue University, June 20–24, 1960. Recommended for publication by the Agricultural Engineering Division.

But technological momentum has created another empty-seat problem that all of industry is facing in this jet age. Its ultimate solution may well be bound up closely with our survival as a world power. The empty seats I'm talking about are those that our fast-moving technology has created for occupancy by the scientists and engineers whom we are failing to provide.

In a recent address, Hilliard Paige, chief of General Electric's missile and space vehicle program, refers to "the crescendo of invention and industrial change" that has been abuilding in this century. Scaling down the 50,000 years of history, which we know about, to 50 years, he says:

> "Man left his cave for some other dwelling ten years ago. He invented writing five years ago. Six months ago, Gutenberg developed the printing press. Two months ago, electricity was discovered. Two weeks ago, the airplane was invented; last week, radio; last Sunday, television and the jet airplane; this morning the first sattellite went into orbit."

Mr. Paige made two other statements that, to me, are equally startling as they also reveal how terribly rapid recent technological progress has been. First, he pointed out that half of all the money this country has *ever* spent on research and development in its entire history of nearly 200 years has been spent since 1950. Second, it has been estimated that despite the growing shortage 90% of all the scientists who ever lived are still alive today!

So we have all these empty seats to fill with scientists and engineers. But here's

where the jet plane analogy breaks down. The commercial airlines are at least blessed with the largest number of paying customers in history. Our technological airline is not so fortunate. Following a drop of 14% in engineering college enrollments since 1957, we will graduate over 10,000 fewer engineers in 1960 than we did in 1950. And by 1965, the federal government says, we may have a deficit of 100,000 engineers.

So with technology moving at supersonic speeds and with a dwindling supply of engineers to man it, industry has a double reason to nurture and cultivate its technical talent: first, to keep pace with progress and, second, to compensate for a declining supply of new talent which must continue to be a grave problem until we find a way to attract more young people to the profession.

Competition of Ideas

We must recognize that we now face a competition of ideas which—in some quarters more rapidly than others—must take precedence over our historic competition of products. I think someone summed it up rather well in the introduction to my company's tuition refund plan when he wrote: "Almost the only competitive advantage one company may hold over another in today's economy is the possession of resourceful, capable, efficient personnel."

Considering today's technology, I think we'd all agree that "engineers and scientists" could be substituted for the word "personnel" without altering the truth of that statement. And considering also the state of world affairs, "nation" could replace "company" to make the observation even more significant.

My purpose is to discuss what industry is doing for the continued education of engineers. And while, until now, that may seem to have been a well kept secret outside your printed programs, I believe no consideration of *what* industry is doing would be complete without a look, such as we have just taken, at the very compelling reasons *why* industry would be doing anything at all. For, though a few companies, like Western Electric, can look back a half century or more to the beginning of formal training programs for their engineers, I think we must admit that most of the activity in this area has come with the same burst of blinding speed that has characterized recent technological progress. On the same scale as Mr. Paige's condensed chronology of invention, most of us began to think seriously about continuing the education of our engineers "only this morning."

I am not at all sure that we have found out in such a short time the best way to do this job. In fact, the variety of methods we've seen in a recent quick look at a few companies leads to the belief that we may never find *one best way*. And perhaps we don't expect to. But more significantly, I believe we can observe that if industry fails to find a best method it won't be from a lack of willingness to experiment with many methods during the search.

So I would like to try to tell you some of the things I think industry *should* be doing and document the ideas by citing some actual cases in which it is doing them.

I believe the most important job industry has to do in this area is to create the kind of climate in which an engineer will *want* to continue his education independently—with or without aid from his employer, with or without opportunity proffered to him. Without this climate, all our formal programs, all our seminars and forums, all our refunded tuitions would be wasted.

Facilities and financial support for engineering programs are a part of such a climate. According to estimates, United States expenditures for research and development will reach $12.4 billion annually in 1960—more than twice the amount we spent only six years ago. Industry will provide between 35 and 40% of the funds and will administer some 75%. As a case in point, my own company's $38 million for engineering and research in 1959 was nearly three times the amount we spent in 1949 and 80 times our R and D expenditure in 1909.

Important as it is to put our money where our mouth is in research and engineering, it's only part of the effort to

create the kind of climate we're talking about. Perhaps it's only a small part. The rest of it eludes all our measuring devices and all our computers. It includes such things as the interest and encouragement we offer, the guidance we give, the decisions we make, the examples we set. Of course, I am talking in large part about the kind of management we are establishing for engineering and research operations. A good boss in the engineering department can do more for the kind of climate we want than the best facilities and the biggest operating budgets could ever provide alone. Where we find such men ready-made, so to speak, we are indeed fortunate. But if we are interested in the continued education of our engineers, it would seem we have a basic responsibility to insure the continued development of their bosses.

Increasing Opportunities

So it's encouraging to learn, as I have from so many companies during preparation of these comments, about increasing educational opportunities specifically for engineering management men. U. S. Steel's 41-week Engineering Management Development Program is a good example of a thoughtfully formulated, company-operated plan. Boeing Airplane Company's program, aimed at "improving managerial and administrative skills of engineering managers," includes such things as university-sponsored study in advanced management and Sloan Fellowships covering a full year of work at M.I.T. and Stanford.

My own company offers opportunities for management study at Northwestern University's Institute for Management, a full-time, on-campus summer session, and in the University of Chicago's Executive Program, a two-year schedule of night classes which can lead to a master's degree in business administration. We are selecting engineering management men—along with those from other departments—for both of these programs. And I think it is interesting that more than 20% of the 75 students from 54 different firms currently participating in the latter program are engineers or research people.

This education for engineering management has another facet which we should not overlook. If engineers are to have the kind of goals in industry that will sharpen their appetities for self-development, the higher executive positions must be open to them as they are to the manufacturing man and the salesman. Some people feel there is cause for concern today in the fact that, with international affairs turning more and more on technological development, too few of those high in our government have a technical background. Failure to face the facts of our time can result in a similar situation in industry.

So, again, it is encouraging to hear from such companies as American Telephone and Telegraph that "engineers in our business are considered along with men having other backgrounds for our management development programs and for outside university executive programs dealing with the principles, practices and skills of management." Such attitudes as this in industry are designed to help bridge the gap between the humanities and the sciences which G.E.'s Mr. Paige calls "the gap between the engineering profession and the rest of the American public."

My own company's Special Management Trainee course, which has counterparts in a number of firms, is another example of activity in this area. Our fourth group of SMT's, which this month is about to complete the three-year course, is composed of 25 men from every major division of the Company. And eleven of them are either engineers or research people. Aimed at men already filling important positions with the Company and at those who have shown evidence of potential for promotion to such positions, SMT is basically on-the-job training, supplemented each year with two weeks of centralized classroom work on such subjects as business management, economics, company organization, policies and functions, etc. Special assignments, job rotation, college courses and self-development round out the SMT's course of study. At its conclusion, the executive head of each operating and staff unit reviews and reports

annually to an SMT policy committee on the progress and current status of graduates.

Not Only Administrators

But what about the engineer who wants advancement but who is not interested in setting his sights on the administrative goals? Like the dedicated researcher in academic life who has no designs on the dean's job, there are many engineers who are repelled by the thought of being manager of the department.

Monsanto Chemical Company, for one, offers what it calls a Senior Scientist and Technologist program. This makes it possible for any engineer to advance to a position of Senior Technologist and receive as much in salary for his technical ability as do others of equivalent skill and experience for administrative responsibilities. Likewise, General Electric's Engineering and Science program carefully points out two career paths for engineers: the path of management and the path of continued close alliance with technical work.

Though I could not begin, here, to present more than a fraction of the evidence, there is reason to believe that industry is aware of a great need to create the kind of atmosphere which will stimulate engineers to greater efforts in self-development.

We have been talking about a vital—though somewhat indirect—aspect of continued education for engineers. And while we have found a very measurable amount of industry activity, it would seem to represent only a small portion of the total effort expended for the development of engineers. Of sixteen firms we queried, only three failed to send evidence of specific advanced learning opportunities of a technical nature for engineers. One of the three employed few engineers, one said its program was up for review and possible alteration and the third reported some activity but no "formal" program.

Two of the firms questioned appear to rely almost entirely on outside educational institutions while three seem to concentrate most of their activity in company-centered programs. But the majority use a combination of the two approaches. While there was great variety in the thirteen detailed responses to our questioning, it would seem that tuition refund programs in cooperation with colleges and universities compose one common denominator among them. I think we must conclude that, in general, this plan has been widely tested and found effective. Though some firms tend to be more or less liberal, 100% refund upon successful completion of a course is a widely accepted practice. In addition, Boeing, for example, provides supplemental payment of $20 per quarter hour or $30 per semester hour (assuming satisfactory grades) for courses in pursuit of advanced engineering degrees.

My own company is now in its fourth year of experience with such a plan and while I do not offer it as typical, I do believe it indicates that the tuition refund idea has been accepted rather well by engineers in particular. In its first three years of operation, our plan attracted an average of 654 students per year. And of that number each year, nearly a third were from our engineering and research departments. When you consider that these departments represent only about 6% of our total manufacturing and raw materials employment, that one-third becomes quite a meaningful figure. As many as 7% of our total engineering employees have participated in the program in a given year compared with the best company-wide per cent of 1.5. Engineers have also consistently accounted for more than one-third of the number of tuition refund people working on degrees.

Tuition refund's emphasis on individual responsibility seems to make it attractive to the companies as well as to the engineers. Time and again, in the industrial program literature we have seen, this disposition to make the engineer responsible for his own attainment is echoed and reechoed.

DuPont, for example, makes it the keystone of its entire plan. This firm's policy "is based on the philosophy that each person is an individual with his own problems, needs and abilities; that his de-

velopment is continuous and that he must accept his share of responsibility for it. His department, through its supervision, must supply the guidance, stimulation and opportunity through job assignment, supplemented with both general and technical formal training courses." As a result, duPont believes, an engineer's development need not fall into standard programs and patterns. Such a policy makes training more difficult and requires more supervisory time, the firm admits. "But engineering department management believes it yields better results."

In close and frequent consultation with supervisors, young duPont engineers map their own professional development plans on the basis of their first five years, five to ten years and ten years to retirement. The plan is organized under eight different headings: professional experience, field of interest, professional consciousness, cultural awareness, community responsibility, health, avocational interests and spiritual depth. As a footnote, you may be interested to know that duPont makes use of ECPD publications for further reading.

Monsanto depends heavily on a somewhat similar approach. Its Performance Review program is the focal point in its development of engineers. It "provides for an annual appraisal of the engineer's performance made by his superior and shared with him in a follow-up interview." A position description and bench marks set in advance by engineer and supervisor in collaboration form the background for the appraisal.

"As a part of the very frank discussion that occurs during the interview," Monsanto says, "plans are made for the engineer's development activities in the years ahead." Plans include special educational activities, job diversification, and individual coaching. Monsanto looks on this program as educational in itself—for both the engineer and his boss.

Judging from the number of firms which also use this approach in some form, it would seem that individual performance appraisal holds a position of importance in the continued education of engineers.

Breadth Too

In any consideration of recent technological progress, acceleration is one problem, mass is another. Industry's engineering and research effort is also growing in size and complexity. Engineer development concepts we've just been talking about aim to keep engineers from getting lost in the organization, buried in some corner where they are almost certain to lose interest and motivation. As the organization grows, there is some tendency to pigeonhole the engineer, to "specialize" him without proper evaluation of his interest and ability. As a part of his continued education and development, it only makes sense to give him a broad sampling of the organization's total effort.

A growing number of firms have adopted a practice of rotating job assignments as a part of their programs. Goodyear's so-called squadron training program is an example and they have a similar 18-month plan in research and development. Commonwealth Edison puts newly hired engineering graduates through a year of rotating job assignments. The Motor Truck Division of my own company has an 18-month program of this kind.

Along this line, Boeing, in 1957, began offering a two-year internship to newly hired graduate engineers. No one had to take it; in fact, it had to be applied for. Each man was told he could spend no more than eight months on any one kind of engineering job. On-the-job training was supplemented by lectures two hours a month. The program was originated by George C. Martin, a Boeing vice president, who believes "the best talents of young engineers are, like gold, worth a good deal of digging to uncover." He also believes engineers should be capable of varied work.

Boeing found that most of the first group of interns were amazingly adaptable, doing almost equally well on every assignment. Another significant number seemed to shine brightest on one or two jobs, making it fairly obvious that the program is valuable for placement as well as for training. To begin with, the

company accepted only 25 engineers a year as interns. It now has a waiting list of 600 eligible applicants and is planning to expand the program.

I will not attempt to list—even from the small sampling we have taken for this paper—all the plans industry is currently offering for the continued education of engineers. But I would like to discuss three of them very briefly as examples of (1) oustanding company-centered approach, (2) an unusual leave-of-absence-for-study idea, and (3) a unique blend of the first two.

Western Electric's Graduate Engineering Training Program is a full-time, off-the-job, all-expenses-paid tour designed for all engineers, both new and experienced. It is offered at three company training centers and its faculty is made up of qualified WE engineers, college professors and professional consultants. For the new engineer the program is aimed at smoothing the transition from academic life and at bringing him rapidly to the point of full productivity. For all engineers, it purports to expand knowledge and skills, stimulate creativity and broaden understanding of the company.

After his first six weeks on the job, a new engineer goes to one of the training centers for nine weeks of technical study related to the manufacture and installation of electrical equipment by the company. After six months more on the job, he takes another nine weeks at the center for courses more specific in nature which provide increased depth in a range of technical subjects essential to his work.

The program's third phase is advanced development and is designed for experienced engineers, including those who have finished the first two phases. It covers a variety of four-week courses on fundamental and theoretical subjects and is set up to continue the engineer's development throughout his career. Western Electric says some 4,500 of its engineers have participated in some part of the plan in the three years it has been in operation.

For an unusual leave-of-absence idea, we saw nothing in our small survey quite like Monsanto's plan. Though it is quite limited in application, it certainly underscores industry's newly acquired awareness of the importance of continued education for engineers. Each year, Monsanto picks two engineers for a full year of graduate study in fields of their own choice, at any recognized university. During that year, their full salaries continue and Monsanto pays for all tuition, books and fees, plus a "modest" relocation allowance. "It goes without saying," Monsanto says, "that this is a much-sought-after prize among our technical people."

Then there is the third example that I wanted to mention which, in a way, combines some aspects of the other two. I know many of you have read about the New York University Graduate Center at Bell Laboratories.[1] Started three years ago, this fascinating experiment in graduate engineering education sets up an arm of a degree-granting university graduate school right on company property. Thus Bell engineers can get full tuition refunded for study toward a graduate degree and time off from work to attend classes with no reduction in salary.

The program evolved from Bell's desire "to impart a common body of basic knowledge to its young college engineering recruits." After trying other methods, it was decided that a university-administered graduate school right at the laboratories might provide the best answer in the combined interests of the students, the university and the company, itself. A year ago this month, as you probably know, degrees were conferred on the first 95 successful candidates to emerge from the Center. Without attempting an evaluation of the plan, as NYU's Professor Shamis did very ably in his ASEE paper last year, we must observe that this stands as a notably significant project in industry's effort to continue the education of its engineers.

[1] Sidney S. Shamis, "The New York University Graduate Center at Bell Laboratories," JOURNAL OF ENGINEERING EDUCATION, Vol. 50, No. 7 (March, 1960), pp. 587–590.

No Pampering

Out of all the variety of programs and plans which we have scanned in recent days, I believe one fact emerges which needs emphasis. I am impressed that none of these are pampering activities staged by benevolent and paternalistic employers. And I don't think they should be. Industry is offering to refund tuition; but the student must pass his course to get it. Industry is offering opportunity; but the offer has to be accepted and acted upon. Industry is trying to create climate conducive to continued education; but it remains for the engineer to respond.

So these are not something-for-nothing programs. You can't spoon-feed curiosity into a man or pamper him into creativity. But if you can get him to stretch his brain, to reach far out beyond the farthest point to which his intellect has ever taken him, he is likely to come back with an idea. I believe most of these plans and programs are aimed at keeping engineers in condition for—if not luring them into—such cerebral gymnastics. This is our main hope in the new competition of ideas in which industry finds itself.

I doubt that any one of us in industry would claim he has the perfect answer for continued engineering education. Almost anything we're now doing may be subject to change or to cancellation and a fresh start.

Perhaps, like General Electric in its so-called Creative Engineering program, industry should seek more directly to develop "deliberate inventiveness." Perhaps we should look again at our evaluation of individual creativity in perspective with team work and group effort to see if our emphasis may be faulty.

And it's possible that along with the technical training opportunities we are offering, we should be doing more to urge continuation of the engineer's nontechnical education. We are hearing more and more about changes in undergraduate engineering curricula to admit a larger serving of the humanities. In fact, industry, itself, is recommending this change, according to a recent survey conducted by the Farm Equipment Institute. What is industry's responsibility in the effort to jump the gap we have noted between the engineering profession and the rest of the American public?

Or perhaps we need a little more of the kind of climate that is apparently producing so many new ideas (as well as new profits) for the Aerojet-General Corporation. According to a recent article in *Business Week*, the entire organizational structure of this unorthodox firm is designed not only to turn up new ideas but to give its engineers and scientists free rein both to develop and exploit them. Aerojet's method has produced eminently good results in defense industry where highly complex technology has made an acute problem of the integration of technical and scientific personnel into business organizations. The idea may never be widely accepted elsewhere in industry, but technological progress may be pushing many firms closer to some variation on the theme.

But whatever we do, should we not speak out more boldly for new ideas as opposed to new products? Not that we would minimize the importance of products in our economy but that we would supply a stronger voice for ideas. Our brief industrial history has already established a high mortality rate for products. And it will only continue to rise in the future. Technology will see to that. But ideas can be timeless. A small case in point: Harvester researchers are currently working with a hydrostatic transmission. As applied to farm tractors, it's new enough that when we announced we were working with it, both the trade and popular press took considerable note. And yet, as we pointed out to them, basic theories for the transmission have been known for at least 30 years. And some of the physical principles involved go back to Archimedes.

The key word, of course, is still competition. But increasingly, it's competition of ideas. Or—if you will—a competition for the men who can generate them.

Survey of First Degree Courses in Mechanical Engineering

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During 1958 the writer visited a number of university engineering schools and colleges of technology in the United Kingdom, on the Continent of Europe, and in North America in order to study their mechanical engineering courses.

In what follows, an attempt will be made to compare and comment on entrance standards, length and content of courses, types of course, and industrial training requirements, in these institutions and in some of the Australian universities.

Information has been obtained by means of verbal and written enquiries, and from university calendars and handbooks, some of which have not proved at all easy to interpret. Although there will no doubt be some minor errors, it is hoped that no serious inaccuracies will appear in the text or in the tables. Most of the figures quoted apply to the 1958 academic year for Australia and to the 1957/8 session for other areas.

Entrance Standards

All of the institutions listed have certain minimum standards for entry to their professional mechanical engineering courses, but in many cases these are relatively unimportant, because competition for a limited number of places means that in fact students have to reach a considerably higher standard in order to gain admission. The minimum standards referred to are usually intended to ensure that a student entering a degree course should have received a reasonably good general education, though some do require would-be engineering students to have achieved a certain definite standard in mathematics and physics. Generally, however, a student's achievement in these particular fields is tested by the examinations which form a part of all selection procedures where these exist.

Although it is obviously impossible to make an accurate comparison of entrance standards, it appears that there are three distinct levels—A, B, and C—corresponding respectively to average secondary-school leaving ages of 16–17, 17–18, and 18–20.

The A level applies only to junior matriculation at some Canadian universities.

The B level applies to the other Canadian universities, all the U.S. universities listed, all Australian universities, the Scottish universities and those in Italy.

The C level applies to all English and Welsh universities and to the remaining Continental institutions.

When comparing the total hours of class attendance in the different courses in a later section, the difference in entrance standards will be allowed for by regarding the B level as normal, by adding 400 hours to the totals for courses in Group C and subtracting 400 hours from the totals for courses in Group A.

Only three of the institutions listed require industrial training as a pre-requisite for entry to mechanical engineering courses—The Technical Universities at Aachen, Trondheim, and Zurich.

Selective entry is the rule at all universities in the United Kingdom and in some of the Continental and North American institutions. Up to the present all Australian university engineering schools accept any matriculated student who applies for enrolment. Where there is competition for a limited number of places, the methods of selection vary to some extent from institution to institu-

tion, but usually take into account one or more of the following:

(a) Secondary school record as evidenced, for example, by ranking in the final year at high school.
(b) Report of secondary school headmaster.
(c) Performance in school leaving examinations set by:
  (i) local education authority;
  (ii) national education authority;
  (iii) universities or groups of universities.
(d) Performance in university entrance examinations set by:
  (i) individual universities or colleges;
  (ii) testing organisations such as Education Testing Services of Princeton.
(e) Result of a personal interview.

Table 1 shows the average age of entry, the level at entry relative to Group B institutions, whether selection is practised, and the pre-requisite industrial training requirements.

TABLE 1

ENTRANCE REQUIREMENTS

Countr	Institution	Average Age of Entry—Years	Relative Level at Entry—Years	Method of Entry	Pre-Requisite Ind. Training
England and Wales	All	18–19	+1	Selective	—
Scotland	All	17–18	—	Selective	—
Denmark	Technical University Copenhagen	18–20	+1	Selective	—
France	L'École Centrale des Arts et Manufactures Paris	20	+2	Selective	—
Switzerland	Lausanne	19	+1	Non-Selective	—
	Zurich	19	+1	Non-Selective	6 months
Holland	Technical Universities Delft and Eindhoven	17–19	+1	Non-Selective	—
Italy	All	19	—	Non-Selective	—
Norway	Technical University Trondheim	19–20	+1	Selective	200 days
Sweden	Technical Universities Gothenburg & Stockholm	20–21	+1	Selective	—
West Germany	Technical University Aachen	19	+1	Non-Selective	3 months
Canada	McGill, Montreal	16–17	−1	Non-Selective	—
	Queens, Kingston	17–18	—	Selective	—
	Toronto	17–18	—	Selective	—
	British Columbia	16–17	−1	Non-Selective	—
United States of America	Carnegie Tech.	18	—	Selective	—
	Cooper Union	18	—	Selective	—
	Cornell	18	—	Selective	—
	Illinois	18	—	Selective*	—
	M.I.T.	18	—	Selective	—
	Pennsylvania	18	—	Selective	—
	Pittsburgh	18	—	Selective	—
	Purdue	18	—	Selective†	—
Australia	All	17–18	—	Non-Selective	—

* Selection applies only to students from outside the State of Illinois.
† Selection applies only to students from outside the State of Indiana.
Note: Figures for average age of entry are mostly taken from the Report of the E. U. S. E. C. Conference on Engineering Education.

The engineering school which probably has the highest entrance standard of all is L'École Centrale des Arts et Manufactures in Paris. It has a competitive entrance examination comprising eleven written and seven oral tests covering mathematics, mechanics, physics, chemistry, mechanical drawing, architectural drawing, French composition, and a modern language other than French.

The standard is such that students who have completed the normal French university matriculation requirements generally need to spend two further years in preparation for it. Even then, only about 1 candidate in 9 is successful. It is claimed that French engineering schools of this type have an overall failure rate of only 1 or 2% compared with figures of 10 to 50% in other parts of Europe. No doubt this is due to the relative shortness of the course (3 years) and the extreme severity of the entrance examination.

While none of the institutions practising selective entry showed any inclination to abandon this practice, a number of them seemed to be dissatisfied with the results of the selection methods they were using. Both in the United Kingdom and the U.S.A. engineering schools of high standing receive ten times as many applications as they have vacant places and most students apply to a number of different institutions. The resulting waste of time in dealing with overlapping applications must be considerable and the performance of selected students is often far from satisfactory. At Imperial College, London, for example, it was stated that it was not unusual for 25% of students to fail their first year, in spite of the fact that the 260 first-year engineering students were selected from about ten times that number of applicants.

In the Australian engineering schools, where selective entry is not practised, the overall failure rate (in 4- or 5-year courses) is estimated to be about 45%. With such a system, it is clear that a large number of students who lack the ability to complete a course of professional engineering training enter the engineering schools and overload the facilities provided.

On the other hand a recent investigation by the author into the entrance qualifications of mechanical engineering graduates from the University of New South Wales between 1952 and 1959 showed that, if selection methods of the English type had been used, an appreciable number of men who secured their Bachelor of Engineering degrees with First or Second Class Honours, would have been prevented from entering the University.

There is good reason to believe that, provided a student has reasonable ability, the major factor contributing to success in a university engineering course is enthusiasm for the course being studied. This enthusiasm for study seems in so many cases to develop after the student has entered the university, that selection at the end of the first year appears much more likely to produce the right results than selection at entry.

Another factor which renders unreliable selection at entry is the marked variation which usually exists in the standard of preparation in secondary schools of different types. Selection based on first-year university results at least has the advantage that the students not only sit for common examinations, but are prepared for them in similar classes working under similar conditions. In addition, the examinations are usually set and marked by people who have been directly involved in providing the instruction.

Length and Content of Courses

The length of first degree courses varies from country to country and in some cases there is even a variation in the one country. Of the courses investigated, the shortest in terms of both hours and years is the "Fast" Honours Course at Cambridge which requires about 1100 hours of class attendance spread over two normal academic years plus part of the long vacation. The longest is the 5-year course at the Politecnico di Torino (Technical University of Turin) which requires almost 5000 hours of class attendance. The course at the Danish Technical University at Copenhagen requires a minimum attendance of 5½ years, but one full year is devoted entirely to instruction in workshop technology followed by practical experience in industry.

As indicated in the previous section there are considerable differences in the standards of entry to first degree courses in engineering, but these are not entirely responsible for the differences in the length of courses.

While it is impossible to make exact comparisons of standards, it is probably fair to say that first degree courses in the United Kingdom, Australia, and the better universities of North America, reach approximately the same level. First degree courses in most Continental universities reach a standard approaching that of the Master's degree in United Kingdom, North American, and Australian universities.

It is, of course, impossible to assess the standard of a course solely on the basis of the total class hours included in it. Even if due allowance is made for differing entrance standards, there are many other factors which cannot be assessed in terms of hours. For instance in considering courses at Oxford and Cambridge, it is impossible to assess in terms of hours the effect of the tutorial system which is a special feature of these universities. The distribution of total hours between the different subjects and groups of subjects does, however, give a useful indication of the relative importance attached to them by the institution concerned.

Tables 2A, 2B, 2C, 2D, and 2E give the length in years and details of the hours of class attendance prescribed for the different subjects included in first degree courses in mechanical engineering in a number of different countries. The subjects are divided into four groups and the percentage of the total hours allocated to each of these groups is shown.

The groups and the individual subjects included in them are as follows:

Basic Science:

Mathematics; Physics; Chemistry (including Engineering Chemistry or Metallurgy); Geology

Engineering Science:

Surveying
Theory of Structures, Strength & Properties of Materials, Statics
Theory of Machines, Dynamics
Fluid Mechanics
Thermodynamics and Heat Engines
Electrical Engineering

Engineering Applications:

Mechanical or Workshop Technology
Engineering Drawing and Mechanical Design
Miscellaneous Engineering (including Professional Electives, Seminars, Thesis Work)

Non-Technical:

Humanities
Management Subjects

For purposes of comparison four areas may be considered:

North America
The United Kingdom
The Continent of Europe
Australia

On the average, the United Kingdom courses are the shortest and the Continental the longest, with courses in Australia and North America of very much the same length.

Within each area there are wide variations in total hours and in the hours allocated to each group of subjects. Table 3 shows, for each area, the range of hours and the average hours allotted to each section, together with the corresponding totals. Table 4 shows in addition the percentage of the total hours allocated to each section.

The following features of Tables 2A, 2B, 2C, 2D, and 2E appear worthy of comment:

(a) The most usual length for courses in the four areas considered is: United Kingdom 3 years, Continent of Europe 4½ years, North America and Australia each 4 years.
(b) In the United Kingdom and Australia it is quite common to have different courses for Pass and Honours degrees while this does not occur in Continental and North American institutions.
(c) The absence of the subject, physics, from almost all English and

TABLE 2A

DISTRIBUTION OF HOURS IN ENGLISH AND WELSH INSTITUTIONS

Institution	Course Length years	Honours or Pass	Maths.	Phys.	Chem.	Total Basic Science	Surv.	S. of M. Statics	Theory of Mach. Dynamics	Fluid Mechs.	Thermo.	Elec. Eng.	Total Eng. Science	Mech. Tech.	E.D. & D.	Misc. Eng.	Total Eng. Applns.	Total Non-Tech.	Grand Total	Percentages			
																				Basic Science	Eng. Science	Eng. Applns.	Non-Tech.
Bristol University	3	H	360	—	72	432	—	240	164	136	244	240	1,024	—	216	—	216	72	1,744	24.8	58.7	12.4	4.1
	3	P	264	—	72	336	—	216	164	160	196	240	976	—	216	—	216	144	1,672	20.1	58.4	12.9	8.6
Birmingham University	3	H/P	216	158	64	438	—	170	162	488		296	1,116	120	234	—	354	—	1,908	23.0	58.4	18.6	—
Birmingham College of Technology +	3	H/P	345	—	180	525	—	390	270	300	315	180	1,455	—	141	—	141	—	2,121	24.8	68.5	6.7	—
Cambridge University	2	HF	50	—	8	58	72	200	139	72	163	152	798	8	152	60	220	12	1,088	5.3	73.4	20.2	1.1
	3	HN	52	—	8	60	74	244	85	59	165	202	829	14	217	16	247	14	1,150	5.2	72.1	21.5	1.2
Leeds University	3	H/P A	126	—	21	147	14	150	79	126	136	79	584	—	441	140	581	42	1,354	10.8	43.2	42.9	3.1
	3	H/P B	126	—	21	147	14	129	79	79	79	58	438	—	441	177	618	262	1,465	10.0	30.0	42.1	17.9
London University: King's College	3	H/P	175	—	75	250	75	295	117	168	235	250	1,140	—	154	350	504	—	1,894	13.2	60.2	26.6	—
Queen Mary College	3	H/P	175	—	26	201	—	106	163	132	135	100	636	—	150	355	505	50	1,392	14.4	45.7	36.3	3.6
University College	3	H/P	216	—	—	216	—	270	302	250	250	396	1,468	54	337	—	391	—	2,075	10.4	70.8	18.8	—
Manchester College of Technology ×	3	H	263	20	142	425	—	241	194	141	171	239	986	61	315	200	576	155	2,142	19.8	46.1	26.9	7.2
	3	P	236	20	142	398	—	193	184	106	201	209	893	61	324	80	465	101	1,857	21.5	48.1	25.0	5.4
Newcastle King's College	3	H	350	—	—	350	—	225	75	100	225	225	850	25	225	225	475	75	1,750	20.0	48.5	27.2	4.3
	3	P	250	—	25	275	—	187	25	50	138	225	625	25	150	150	325	125	1,350	20.4	46.3	24.1	9.2
Sheffield University	3	H	240	—	60	300	—	215	177	120	264	156	932	72	120	—	192	—	1,424	21.1	65.5	13.4	—
	3	P	168	—	60	228	—	167	201	120	288	156	932	120	240	—	360	48	1,568	14.5	59.4	23.0	3.1
Swansea University College ϕ	3	H/P	172	—	50	222	—	271	304	150	192	201	1,118	—	375	—	375	40	1,755	12.6	63.7	21.4	2.3

Notes: HF = Fast Honours Course; HN = Normal Honours Course; H/P = Same Course for Honours and Pass Degrees. H/P A = Honours and Pass Course, Option A; H/P B = Honours and Pass Course, Option B; ϕ Course leading to B.Sc.(Eng.) of University of Wales. + Course leading to B.Sc.(Eng.) of London University; × Courses leading to B.Tech. of Manchester University.

College ϕ																							

Notes: HF = Fast Honours Course; HN = Normal Honours Course; H/P = Same Course for Honours and Pass Degrees. H/P A = Honours and Pass Course, Option A; H/P B = Honours and Pass Course, Option B; ϕ Course leading to B.Sc. (Eng.) of University of Wales. + Course leading to B.Sc. (Eng.) of London University; × Courses leading to B.Tech. of Manchester University.

Table 2B

Distribution of Hours in Institutions in Scotland and Northern Ireland

Institution	Course Length Years	Honours or Pass	Maths.	Phys.	Chem.	Total Basic Science	Surv.	S. of M. Statics	Theory of Mach. Dynamics	Fluid Mechs.	Thermo.	Elec. Eng.	Total Eng. Science	Mech. Tech.	E.D. & D.	Misc. Eng.	Total Eng. Applns.	Total Non-Tech.	Grand Total	Percentages			
																				Basic Science	Eng. Science	Eng. Applns.	Non-Tech.
Aberdeen University	4	H/P	496	260	172	928	—	←	402	→	344	144	890	—	616	130	746	—	2,564	36.2	34.7	29.1	—
Edinburgh University	3	H	282	156	156	594	56	259	136	121	153	202	927	—	364	394	758	54	2,333	25.4	39.7	32.5	2.4
	3	P	282	156	156	594	56	259	136	121	153	202	927	—	442	316	758	54	2,333	25.4	39.7	32.5	2.4
Glasgow Royal College of Science & Technology	4+	H/P	230	310	160	700	—	129	129	54	450	270	1,032	40	450	200	690	—	2,422	28.9	42.6	28.5	—
St. Andrews University	4	H	425	260	260	945	83	201	120	216	160	235	1,015	—	315	—	315	—	2,275	41.5	42.7	13.8	—
	4	P	350	260	260	870	83	201	70	116	110	235	815	—	315	—	315	—	2,000	43.5	40.8	15.7	—
Belfast Queen's University	3	×H	275	75	—	350	75	120	95	110	450	200	1,050	100	525	—	625	—	2,025	17.3	51.8	30.9	—
	3	P	275	75	—	350	75	185	155	85	375	200	1,075	100	450	—	550	—	1,975	17.7	54.5	27.8	—

Notes: + Sandwich course leading to B.Sc. Degree of Glasgow University. × Internal Combustion Engines Option.

TABLE 2C

DISTRIBUTION OF HOURS IN CONTINENTAL INSTITUTIONS

Institution	Course Length Years	Maths.	Phys.	Chem.	Total Basic Science	Surv.	S. of M. Statics	Theory of Mach. Dynamics	Fluid Mechs.	Thermo.	Elec. Eng.	Total Eng. Science	Mech. Tech.	E.D. & D.	Misc. Eng.	Total Eng. Applns.	Total Non-Tech.	Grand Total	Percentages			
																			Basic Science	Eng. Science	Eng. Applns.	Non-Tech.
Aachen	4½	240	168	24	432	—	132	324	148	500	180	1,284	348	376	964	1,688	56	3,460	12.5	37.1	48.8	1.6
Delft	5	286	78	65	429	—	207	243	150	490	186	1,276	192	669	650	1,511	—	3,216	13.4	39.6	47.0	—
Gothenburg	4½	476	154	112	742	—	308	308	196	322	112	1,246	224	350	770	1,344	140	3,472	21.3	35.9	38.8	4.0
Stockholm ×	4½	525	189	28	742	—	410	164	140	420	112	1,246	119	427	343	889	133	3,010	24.7	41.4	29.5	4.4
Lausanne	4½	601	279	81	961	—	517	93	662	481	1,067	2,820	—	960	130	1,090	78	4,949	19.3	57.0	22.1	1.6
Zurich	4½	565	238	62	865	—	301	122	350	310	132	1,215	130	892	656	1,678	144	3,902	22.1	31.2	43.0	3.7
Trondheim	4½	480	273	64	817	—	243	112	281	490	145	1,271	145	956	968	2,069	252	4,409	18.5	28.8	47.0	5.7
Turin	5	608	477	+716	1,801	68	558	369	189	486	230	1,900	122	702	378	1,202	94	4,997	36.0	38.0	24.0	2.0

Notes: × Power Engineering Option. + Includes 108 hours of Mineralogy and Geology.

TABLE 2D

DISTRIBUTION OF HOURS IN NORTH AMERICAN INSTITUTIONS

Institution	Course Length years	Maths.	Phys.	Chem.	Total Basic Science	Surv.	S. of M. Statics	Theory of Mach. Dynamics	Fluid Mechs.	Thermo.	Elec. Eng.	Total Eng. Science	Mech. Tech.	E.D. & D.	Misc. Eng.	Total Eng. Applns.	Total Non-Tech.	Grand Total	Percentages			
																			Basic Science	Eng. Science	Eng. Applns.	Non-Tech.
Queen's University, Kingston	4	384	438	270	1,092	54	203	81	148	621	270	1,377	500	189	—	689	284	3,442	31.8	40.0	20.0	8.2
McGill University, Montreal	5	410	385	373	1,168	86	215	301	186	388	125	1,301	135	561	173	869	379	3,717	31.4	35.0	23.4	10.2
Toronto University	4	299	234	247	780	52	266	182	299	416	260	1,475	52	715	—	767	260	3,282	23.8	45.0	23.3	7.9
University of British Columbia, Vancouver	4	392	238	350	980	152	⟵ 882 ⟶		84	182	280	1,580	392	174	126	692	308	3,560	27.5	44.4	19.4	8.7
Carnegie Tech., Pittsburgh	4	210	247	225	682	—	165	90	180	375	150	960	—	210	210	420	450	2,512	27.2	38.2	16.7	17.9
Cooper Union New York	4	240	285	270	795	60	150	255	75	165	90	795	150	105	165	420	405	2,415	32.9	32.9	17.4	16.8
	+8	225	270	240	735	—	98	172	98	172	180	720	30	180	225	435	330	2,220	33.1	32.4	19.6	14.9
Cornell University, Ithaca	5	231	308	196	735	—	315	168	105	196	189	973	525	315	560	1,400	294	3,402	21.6	28.6	41.2	8.6
University of Illinois, Urbana	4	240	360	240	840	—	390	450	30	450	165	1,485	—	540	150	690	180	3,195	26.2	46.5	21.7	5.6
Massachusetts Institute of Technology Cambridge	×4	168	280	252	700	—	112	98	56	98	56	420	42	350	392	784	336	2,240	31.3	18.7	35.0	15.0
	ϕ4	252	336	252	840	—	112	98	56	42	56	364	—	224	350	574	336	2,114	39.7	17.2	27.2	15.9
University of Pennsylvania Philadelphia	4	256	400	192	848	—	136	64	72	320	144	736	160	192	384	736	464	2,784	30.5	26.4	26.4	16.7
University of Pittsburgh Pittsburgh	4	352	208	272	832	—	176	176	48	368	128	896	80	528	128	736	640	3,104	26.8	28.9	23.7	20.6
Purdue University Lafayette	4	336	320	288	944	—	136	200	112	328	160	936	96	264	256	616	384	2,880	32.8	32.5	21.4	13.3

Notes: + Part-time evening course. × Power and propulsion option. ϕ Engineering science option.

TABLE 2E

DISTRIBUTION OF HOURS IN AUSTRALIAN INSTITUTIONS

Institution	Course Length years	Honours or Pass	Maths.	Phys.	Chem.	Total Basic Science	Surv.	S. of M. Statics	Theory of Mach. Dynamics	Fluid Mechs.	Thermo.	Elec. Eng.	Total Eng. Science	Mech. Tech.	E.D. & D.	Misc. Eng.	Total Eng. Applns.	Total Non-Tech.	Grand Total	Percentages			
																				Basic Science	Eng. Science	Eng. Applns.	Non-Tech.
University of Adelaide	5	H/P	378	297	135	810	108	378	147	171	183	162	1,149	180	471	63	714	36	2,709	29.9	42.4	26.4	1.3
	×3	H/P	384	192	160	736	—	258	67	80	185	128	718	376	416	128	920	—	2,374	31.0	30.2	38.8	—
University of Melbourne	4	H	388	202	273	863	—	262	90	136	210	260	958	—	508	221	729	26	2,576	33.5	37.1	28.4	1.0
	4	P	388	202	273	863	—	262	90	126	200	260	938	—	470	221	691	26	2,518	34.2	37.2	27.5	1.0
University of New South Wales	+4	H/P	300	252	192	744	Δ—	264	192	216	240	168	1,080	180	444	424	1,048	240	3,112	23.9	34.7	33.7	7.7
	φ7	H/P	272	234	187	693	34	220	170	218	221	170	1,033	136	306	210	652	182	2,560	27.1	40.3	25.5	7.1
University of Sydney	5	H	297	324	162	783	—	333	176	196	196	360	1,261	189	507	603	1,299	—	3,343	22.6	37.6	38.8	—
	4	P	270	324	162	756	—	306	149	169	169	360	1,153	54	507	198	759	135	2,803	27.0	41.1	27.1	4.8
University of Queensland	4	H/P	380	360	θ360	1,100	130	245	245	105	470	220	1,415	200	770	230	1,200	—	3,715	29.6	38.1	32.3	—
University of Western Australia	5	H	416	286	246	948	104	166	324	154	236	234	1,218	36	655	296	987	—	3,153	30.2	38.4	31.4	—
	5	P	416	286	246	948	104	166	324	154	236	234	1,218	36	655	140	831	—	2,997	31.6	40.6	27.8	—

Notes: ×3 year full-time course taken at South Australian School of Mines, Adelaide, leading to B.Tech. degree of Adelaide University. +4 year full-time course on 'sandwich' principle.
φ 7 year part-time course. Δ One week's survey camp—no formal lectures. θ Includes 90 hours of geology.

Welsh courses. This is partly explained by the fact that students entering these courses are required to have reached at school a standard in physics which is at least equivalent to that of the first year of American and Australian university courses. There is also a tendency for material, which elsewhere would be included in physics courses, to be included in one or the other of the engineering science subjects.

(d) The comparatively small total hours provided for basic science in English and Welsh courses due to the higher entrance standards required in all these subjects.

(e) The comparatively small time allowances for all subjects and particularly mathematics and chemistry in the Cambridge courses. These low figures are due to the fact that tutorial work is arranged by the individual colleges and that no specific time allowance is provided for it. The figures shown cover lectures and laboratory work only.

(f) The inclusion of geology in only two courses—those at the Politecnico di Torino and the University of Queensland.

(g) The inclusion of surveying in less than one-third of the courses listed.

(h) The absence of workshop technology or mechanical technology from almost half of the United Kingdom courses.

(i) The extraordinarily generous provisions of time for electrical engineering and fluid mechanics at Lausanne—about five times the average for all other courses in electrical engineering, and about four times the average for all other courses in fluid mechanics.

(j) The marked variation in the time provided for engineering drawing and mechanical design—from 105 hours at Cooper Union and 120 hours in the honours course at Sheffield to 956 hours at Trondheim and 960 hours at Lausanne.

Table 3 shows that in all four areas there is a very wide variation in the total hours included in courses. The variation in the hours allocated to each of the four sections of the course is, however, wider still.

Taking the average of the total hours for each area, it will be seen that the Continental average is 102% greater than that for the United Kingdom, while the

TABLE 3

SUMMARY OF DISTRIBUTION OF HOURS (RANGES AND AVERAGES)

Area	Basic Science		Engineering Science		Engineering Applications		Non-Technical Subjects		Total	
	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average
North America	680 to 1,090	830	360 to 1,580	1,000	420 to 1,400	700	180 to 640	360	2,110 to 3,560	2,890
United Kingdom	460 to 940	670	580 to 1,470	940	120 to 760	440	0 to 150	50	1,490 to 2,560	2,100
Continent of Europe	830 to 1,800	1,200	1,210 to 2,820	1,530	890 to 2,070	1,430	0 to 250	90	3,410 to 5,350	4,250
Australia	690 to 1,100	840	720 to 1,410	1,100	650 to 1,300	890	0 to 240	60	2,370 to 3,720	2,890

TABLE 4

SUMMARY OF DISTRIBUTION OF AVERAGE HOURS (PERCENTAGES)

Area	Hours	%	Hours	%	Hours	%	Hours	%	Hours	%
North America	830	28.7	1,000	34.6	700	24.2	360	12.5	2,890	100.0
United Kingdom	670	31.9	940	44.8	440	20.9	50	2.4	2,100	100.0
Continent of Europe	1,200	28.2	1,530	36.0	1,430	33.7	90	2.1	4,250	100.0
Australia	840	29.1	1,100	38.0	890	30.8	60	2.1	2,890	100.0

Note: In Tables 3 and 4 the times shown for basic science have been adjusted so as to take accou of differences in entrance standard between courses in Groups A, B, and C.

average for both North America and Australia is 38% greater.

The average time allocated to both basic science and engineering science is considerably greater in Continental courses than in any of the other areas, but the difference is even more marked when it comes to engineering applications. Here the Continental average is more than three times that for the United Kingdom.

On the other hand, the allowance for non-technical subjects is very much greater in North America than in any of the other three areas.

Consideration of Table 4 shows that there is very little difference among the four areas in the percentage of the total time allocated to basic science, though the United Kingdom figure is somewhat higher than the other three. In engineering science the United Kingdom percentage is considerably greater than the other three, while in engineering applications, on the other hand, it is definitely the lowest of the four. North American courses allocate on the average 12.5% of the total time to non-technical subjects, while in each of the other three areas the corresponding figure is little more than 2%.

To summarise, it might be said that United Kingdom courses are generally the shortest in total hours and tend to emphasize engineering science at the expense of engineering applications. Continental courses having a much greater time allowance are able to include a very thorough treatment of both engineering science and engineering applications. North American and Australian courses have some advantage in total hours over United Kingdom courses. The former tend to use this extra time for non-technical subjects, while the latter devote it to engineering applications.

Types of Course

The great majority of courses listed are full-time courses requiring between 20 and 30 hours per week of class attendance for from 24 to 32 weeks per year.

In the United Kingdom and Australia the academic year is usually divided into 3 terms of from 8 to 11 weeks each, while on the Continent and in North America the usual arrangement is to have 2 semesters of from 12 to 16 weeks each.

On the Continent all engineering courses at the professional level operate on a full-time basis, but in the other three areas engineering degrees may be obtained by part-time study. The following are examples of this type of course:

United Kingdom:

A number of Colleges of Technology operate part-time courses leading to the External B.Sc.(Eng.) degree of London University. One of these is the part-time course at the Royal Technical College, Salford, which requires attendance for 9–10 hours per week over a period of 6 years.

North America:

A typical part-time course is that leading to the B.M.E. degree at Cooper Union, New York. It requires at-

tendance for about 9 hours per week over a period of 8 years.

Australia:

The only institution operating part-time degree courses is the University of New South Wales. The mechanical engineering course leading to the B.E. degree requires attendance for 10–12 hours per week over a period of 7 years.

Table 5 shows the total hours and the distribution of hours between the different groups of subjects for the three part-time courses mentioned. In the American and Australian courses the total hours are appreciably less than in the corresponding full-time courses provided by the same institutions. It is apparently considered that this reduction in class attendance is justified by the additional industrial experience and maturity of the part-time students.

A third type of degree course which is relatively common in North America, non-existent on the Continent of Europe, and available in only one or two institutions in the United Kingdom and Australia is the sandwich or co-operative course. Courses of this type alternate periods of academic work at the university with periods of industrial training. The length of each period varies from institution to institution, the minimum being usually one month and the maximum six months.

In some cases the student is sponsored by a single employer and goes to him for all his industrial training periods; in others, the university may arrange for the student to go to a different employer for each period.

Sometimes the student is required to find an employer willing to sponsor him, but in other cases, the arrangement of suitable employment is the responsibility of the university.

It is usual for the university to specify the type of employment appropriate to each period of industrial training and to require from each student a written report on the work done in each period. The employer is frequently asked to complete a report form covering the student's work with his company. The degree of co-operation between the university and industry in arranging for industrial experience to fit in with academic training varies considerably from place to place, as does provision by the university for the supervision of its students during industrial training periods by members of the academic staff.

Tables 6A and 6B give details of four co-operative or sandwich course arrangements—one in the United Kingdom, two in North America, and one in Australia.

It is interesting to note that the great majority of the courses run by Colleges

TABLE 5

SUMMARY OF DISTRIBUTION OF HOURS IN PART-TIME COURSES

Institution	Award	Length Years	Ent. Level	Basic Science		Engg. Science		Engg. Applns.		Non-Tech. Subjects		Totals	
				Hrs.	%	Hrs.	%	Hrs.	%	Hrs.	%	Hrs.	%
United Kingdom: Royal Tech. College Salford	B.Sc. (Eng.) London	6	+1	A842	33.1	1,547	60.9	153	6.0	—	—	2,542	100.0
North America: The Cooper Union New York	B.M.E.	8	—	735	33.1	720	32.5	435	19.6	330	14.8	2,220	100.0
Australia: University of New South Wales	B.E.	7	—	693	27.0	1,033	40.4	652	25.5	182	7.1	2,560	100.0

A—hours adjusted to take account of higher entrance level.

TABLE 6A

ARRANGEMENT OF CO-OPERATIVE COURSES (NORTH AMERICA)

Institution	1st Year			2nd Year			3rd Year			4th Year			5th Year		Total	
	S1 Wks.	S2 Wks.	SS Wks.	S1 Wks.	S2 Wks.	SS Wks.	S1 Wks.	S2 Wks.	SS Wks.	S1 Wks.	S2 Wks.	SS Wks.	S1 Wks.	S2 Wks.	Wks.	Wks.
Purdue University	U 16	U 16	U 14	I 18	U 16	I 14	U 16	I 18	U 14	I 18	U 16	I 14	U 16	U 16	U 140	I 82
Cornell University	U 14	U 14		U 14	U 14	U 14	I 14	U 14	I 14	U 14	I 14	U 14	U 14	U 14	U 140	I 42

Note: S1 = First Semester; S2 = Second Semester; SS = Summer Session.

TABLE 6B

ARRANGEMENT OF SANDWICH COURSES (UNITED KINGDOM AND AUSTRALIA)

Institution	1st Year			2nd Year			3rd Year			4th Year			Total	
	T1 Wks.	T2 Wks.	T3 & LV Wks.	T1 Wks.	T2 Wks.	T3 & LV Wks.	T1 Wks.	T2 Wks.	T3 & LV Wks.	T1 Wks.	T2 Wks.	T3 Wks.	Wks.	Wks.
Royal College of Science & Technology, Glasgow	U 11	U 11	I 25	U 11	U 11	I 25	U 11	U 11	I 25	U 11	U 11		U 88	I 75
University of New South Wales	U 12	U 12	U 2 I 22	U 12	U 12	U 2 I 22	U 12	U 12	U 2 I 22	U 12	U 12	U 12	U 114	I 66

Note: T1 = First Term; T2 = Second Term; T3 = Third Term; LV = Long Vacation.

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Denmark		
France		
Germany		
Holland		
Norway		
Sweden		
Switzerland		
United Kingdom		
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of Technology in England and Wales for the new Diploma of Technology award are 4 year courses of the sandwich type with alternating periods of between 5 and 6 months at college and in industry. These courses are to be of the same standard as courses leading to the B.Sc. degree in university engineering schools, but they tend to place rather more emphasis on engineering applications than on engineering science. They must also include a certain number of humanities subjects.

Industrial Training in First Degree Courses

There are marked differences of opinion about the value of industrial training periods for engineering students and consequently requirements vary, not only from country to country, but even between universities in the one country.

Table 7 gives a summary of the requirements in a number of countries.

It will be noted that while all Australian universities and the majority of the Continental universities listed, require industrial training during their degree course; this requirement is much less common in the United Kingdom and the U.S.A. In theUnited Kingdom there is a strong feeling that industrial training is better left until the student has graduated. It is, therefore, still common practice for the new graduate to take an appointment as a graduate apprentice in a large company and spend a period of about two years gaining experience in various phases of its work. At the end of this period, if he holds an Honours degree, or has completed the Part III examinations of the Institution of Mechanical Engineers, he will be qualified for Associate Membership of the Institution and is thenceforth regarded as a fully qualified professional engineer.

TABLE 7

INDUSTRIAL TRAINING REQUIREMENTS

Country	Training Before University Course	Training During University Course
Australia	Not required	3–15 months
Canada	Not required	6–9 months
Denmark	Not required	8½ months practical work before entering university may count towards this
France	Not required	No definite period is specified
Germany	3 months	9 months
Holland	Not required	6 months
Norway	200 days	100 days
Sweden	Not required	6 months
Switzerland	¤6 months	¤3 months
United Kingdom	Not required	* Generally not required
U.S.A.	Not required	Required only in cooperative (sandwich) courses

¤ E.T.H. Zurich only—Lausanne does not require industrial training.
* Cambridge requires 6 weeks and Glasgow (sandwich course) 15 months. Some other universities recommend industrial training but do not require it.

Comments and Conclusions

The average age of entry to first degree courses in engineering varies from as low as 16 years to as high as 21 years. There seems to be considerable merit in having a normal entrance age of about 18 years. Experience in Australia has shown that 16 and 17 year old students frequently lack the maturity to cope adequately with a university course. Even the particularly able ones who can handle the academic work required of them are often too immature at graduation to make an easy transition to professional positions in industry. If the extra year at secondary school were used to provide a transition between school and university methods of study it would almost certainly result in a reduction of the unduly high first-year failure rates reported by so many institutions.

In England and Wales the high entrance standard and the keen competition for university places has led large numbers of boys to stay on at secondary school until the age of 19. This appears to be rather a late age for transfer from school to university, though it is true that in the 6th forms of the better English grammar and public schools an attempt is made to prepare pupils for the transition to tertiary education. An unfortunate feature of the British system is that for the last 2 or 3 years at secondary school a potential engineering student will concentrate almost all of his efforts

Note: T1 = First Term; T2 = Second Term; T3 = Third Term; LV = Long Vacation.

on 3 subjects—Pure Mathematics, Applied Mathematics and Physics or, perhaps, Combined Mathematics, Physics, and Chemistry. This means that his general education finishes at the age of 15 or 16, at which stage he is unlikely to be able to appreciate fully some of the general subjects he is taking.

In many Continental countries the number of subjects taken right to the end of secondary school is considerable. In Sweden for example the final year includes the following:

> Religion, Swedish, German, English, French, history and civics, geography, philosophy, mathematics, biology and hygiene, physics, chemistry, applied art, music, and physical training.

No doubt the student entering a Swedish university has a very good general secondary education, but it has taken him until the age of 20 or 21 to acquire it.

American high schools also seem to aim at giving their pupils a good general secondary education, but, because of the shorter time available, this frequently results in engineering students entering the university with a much less solid grounding in mathematics and physics than their opposite members in the United Kingdom, on the Continent and even in Australia.

In these days the professional engineer cannot hold his own in public affairs with other professional men, unless he has a much sounder general education than has been the case in the past. Some of this can be given at the secondary school level, but there is no doubt that some of the most important humanities subjects can only be properly appreciated by more mature students. This means that room should be found for such subjects in engineering degree courses.

Scarcity of staff and accommodation to cope with the ever increasing number of engineering students will make some system of restriction necessary even in those institutions which do not practice it at present. Existing methods of selection which are based on pre-university performance are far from efficient and certainly exclude some first-class material from university engineering schools. Although this would mean increasing facilities for first-year students, it would seem much more logical to allow all matriculated students to enter the university and then base progression to the later years of the course on first year performance. Methods used by many American universities to exclude students who fail to make satisfactory progress in later years of their course might well be extended to other countries.

With an average entrance age of 18 years, four years appears to be the most reasonable length for first-degree courses.

As knowledge in all fields increases, there is an obvious temptation to put more and more material into such courses. This will inevitably lead to demands from the academic staff for 5-year courses instead of 4, and later, no doubt, for 6-year courses in place of 5.

If a proper selection of material is made, 4 years should be sufficient for a first-degree course. Additional material can then be included in postgraduate courses of a more specialised nature which should be available to the graduate who finds that he must go further in a particular field in order to cope with the job which he wants to do when he leaves the university.

Longer first-degree courses would not be so bad if a reasonable proportion of students actually completed them in the minimum time. On the Continent, however, it is quite common for the average student to take 2 years more than the minimum time to gain his first degree. This applies particularly to those universities like Aachen, Copenhagen, and Delft where students are allowed considerable freedom in deciding when they will sit for their examinations. If a Danish engineering student enters the Technical University at Copenhagen at the average age of 19–20 he may expect to complete his course (5½ years minimum) at the age of about 27. This is a rather late age to be starting work in one's chosen profession, but under existing conditions his situation is even worse, as he has to complete a period of 2 years compulsory military service after graduation. At a time when practically every country is

suffering from a shortage of professional engineers the seriousness of such delays in completing professional training is obvious.

A reasonable allowance of total hours for a four year course appears to be from 2,800–3,000 according to the number of weeks of class attendance.

Placing such a time limitation on the length of first-degree courses means that the basis of selection of material for inclusion is of the greatest importance. Both in America and the United Kingdom there appears to be a strong tendency to increase the time allocaton for engineering science subjects at the expense of engineering applications. The argument in favour of this change is that, as we are training the engineers of the future, it is more important to ensure that they have a sound knowledge of fundamentals than a close acquaintance with applications which may be obsolete within 5 or 10 years. This type of course will undoubtedly suit the student who excels in mathematics and physics, but it may well fail to arouse the interest of the man with only average ability in these subjects. Some North American universities are trying to solve this problem by offering engineering science options in their mechanical engineering courses or by offering separate courses leading to a degree in engineering physics. These options or separate courses are usually open only to those students who have excelled in the mathematics and physics of the earlier years.

Another approach to the problem is that adopted by the University of Sydney, which allows students who have completed the first two years of the Bachelor of Engineering course with sufficient merit in mathematics and physics to spend their third year completing the requirements of the Bachelor of Science degree in either mathematics or physics. They may then return to the engineering school to take the 3rd and 4th years of their chosen B.E. course.

In Continental and North American universities, it is the usual practice for all students aiming at a particular degree to take the same subjects. The award of Honours, where is exists, is dependent on scoring sufficiently high marks in some or all of these subjects. On the other hand, many British and Australian universities provide different programs, particularly in the later years, for Honours and Pass students. With such an arrangement it is impossible for a student taking the Pass course to obtain his degree with Honours, no matter how high his marks.

The variation in ability and application of students entering university engineering schools is so great that it seems only logical to provide courses at two levels at least in the later years.

This will give the average student the opportunity of obtaining a thorough understanding of a limited range of material, while extra work at a higher level is provided to extend the very able student and thus retain his interest.

Although many professional engineers are still being trained in part-time courses in both the United Kingdom and Australia, it is being gradually realised that this type of training is not only unduly hard on the student, but is also extremely inefficient. It is extremely difficult to obtain accurate information about failure rates, but from what is available, it would appear that they are 1½ times or even twice as high as in corresponding full-time courses. The only advantages of part-time training, other than the financial one, are that it gives the student concurrent industrial experience which may help him with his studies, and that it gives both student and employer a chance of finding out whether he is suited to engineering work. The graduate who completes his course without having had any industrial experience is at a very considerable disadvantage when he goes to his first job after graduation, but this deficiency in experience is surely made up much more satisfactorily by having courses of the sandwich type.

An arrangement which has worked particularly well at the University of New South Wales is for an employer to select engineering trainees or cadets at matriculation level and employ them full-time while they do the first two years of the part-time B.E. degree course. At the end of this period those cadets whose

performance both in industry and at the University has warranted it are transferred to the second year of the full-time (sandwich) B.E. course and are paid by the employer while they complete the remaining three years for their degree. This arrangement gives the employer an opportunity of deciding whether it is worth investing the money required to put a particular cadet through the course on a full-time basis. It also provides an incentive for cadets who would prefer full-time to part-time study.

To summarise what has gone before, the following suggestions are made regarding first-degree courses in mechanical engineering:

(a) The entrance standard for these courses should be such as can normally be reached by a student 18 years of age who has completed a 6-year course at secondary school. The secondary course should provide the groundwork for a good general education, but should pay special attention to the mother tongue and to mathematics and physics. An attempt should be made in the last year or two at secondary school to provide a transition from school to university methods of study.

(b) All students who have reached the prescribed entrance standard can be admitted to the first year of their chosen degree course.

(c) Where entry to the second year of degree courses has to be restricted, selection should be based on the student's first-year performance. Some limit (probably two years) should be placed on the time allowed for any student to meet the requirements for proceeding to the second year. Students failing to make satisfactory progress in later years of the course should be excluded from the course.

(d) The course should be of 4-years duration with a total time allowance of 2800 to 3000 hours divided between the different sections in the following way:

Basic Science 30%; Engineering Science 30%; Engineering Applications 30%; Non-Technical Subjects 10%.

If there are enough students to warrant the provision of separate courses for Pass and Honours, or of an engineering science option, the percentages of total hours allocated to basic science and engineering science in the Honours course or the engineering science option should be increased above the figures previously quoted with a corresponding reduction in the allocation for engineering applications.

(e) Although full-time courses have certain advantages, there is much to recommend the co-operative or sandwich arrangement with alternate periods of 20 to 24 weeks devoted to academic study and industrial experience. A compromise arrangement, which may well prove the most satisfactory of all, is to devote the whole of the first year to academic work, thus allowing the student more time to make the difficult transition from secondary school to university, to provide alternate periods of academic work and industrial experience in the 2nd and 3rd years, and to revert to a full year of academic work in the 4th and final year of the course.

The foregoing suggestions are made on the assumption that a reasonable variety of postgraduate courses will be available for the more able students.

References

1. Proceedings of the Third E.U.S.E.C. Conference on Engineering Education. (Paris: September 1957)—The Institution of Mechanical Engineers, London.
2. Calendars and Handbooks of the Universities and Colleges visited.

Mechanics Division Bulletin

Executive Committee

J. O. Smith, Ch.....1961	E. J. Marmo.....1962	D. C. Drucker.....1963
D. R. Carver.....1961	E. P. Popov.....1962	E. C. Clark.....1964
H. R. Lissner *.....1961	F. P. Beer.....1963	I. H. Shames.....1964

Secretary of the Mechanics Division: Lt. John A. Weese, Department of Mechanics, U. S. Air Force Academy, Colorado.

Editor: Arthur W. Davis, Department of Theoretical and Applied Mechanics, Iowa State University, Ames, Iowa.

Chairman's Message

J. O. SMITH

Professor of T.&A.M.,
University of Illinois

Not long after the 1960 Annual Meeting of ASEE our Division representative on the General Council of ASEE asked that a statement of the purpose of the Mechanics Division be forwarded to him for use by the Society. I am glad to respond to this request and would like to greet the members of the Society and of the Mechanics Division with this statement of purpose.

Statement of Purpose. ASEE has been growing rapidly in membership and, like all big organizations, it must constantly re-examine its activities, including that of the divisions, in order to be certain that the Society is serving the purpose for which it was founded, namely, to serve engineering education. As engineering education develops so must the divisions develop.

Newer Trends in Mechanics Division. The recent increase in numbers of curricula in Engineering Mechanics, Engineering Science or Engineering Physics, in the United States has created the need for a forum for discussion of the problems connected with the development of these curricula. The Engineering Mechanics Division has assumed much of the responsibility for providing for such discussions. These discussions have been lively and the large attendance proved that there is a lot of interest in these newer curricula.

There is a growing need in the Society for increased emphasis upon what may be called semi-technical reports on recent developments in the subject matter that are or may be taught in undergraduate engineering. The Mechanics Division has been stepping up its efforts along these lines, too, in the recent Annual Meetings, with one session devoted to such papers at the 1960 Meeting. In order to put further emphasis upon subject matter, as well as upon good teaching techniques, the Division has begun to make changes in the committee structure. We are now in the process of appointing three new committees. These are (1) Mechanics of Solid Deformable Bodies, (2) Mechanics of Fluids, and (3) Dynamics of Rigid and Solid Deformable Bodies. The work of these committees should serve to enrich the Division program and to increase interest in the work of the Division. We hope that they will encourage experimentation with the teaching of newer developments in subject

* Division Representative on the General Council.

matter in the areas that they represent and inject the results into a program.

Expanding Role of Division. The newer aspects of the Division's activities are important, but no change in emphasis upon older roles is anticipated. Among the outstanding services that have been performed by the Mechanics Division are the following: conducting outstanding programs at the annual meetings of the Society at which the best speakers in their respective fields are brought to the meetings; conducting summer schools in the areas of undergraduate and graduate mechanics; preparing and evaluating a standard examination in statics and dynamics; preparing surveys of facts about the type of subject matter taught and the amount of time given to undergraduate courses in mechanics, etc.

Most of us who attend the annual meetings know that one of the most important purposes served by the Division is the informal meetings, outside the more formal programmed meetings, of small groups of persons who are interested in the field of mechanics.

The Mechanics Division welcomes ideas and suggestions for the improvement of the services that we perform for the Society.

COLLEGE–INDUSTRY CONFERENCE

What is PROFESSIONAL CLIMATE?

Do we want it?
How do we develop it?
How do we maintain it?

These and related questions will be answered at the RWI College-Industry Conference to be held at Cincinnati, Ohio on February 2–3. The program will include the following presentations:

What a Company Has Done
What a Consulting Firm Has Done
What a Government Agency Has Done
What a University Has Done
An Experience with Professional Unionism
Professionalism in Industry—A report on the NSPE Survey by an Opinion Research Representative
Professional Climate Study by Faculty Members During Summer Employment

A complete list of speakers will be published in the January issue of the JOURNAL. For further information on the program write: CIC Committee, College of Engineering, University of Cincinnati. Headquarters for the conference will be the Hotel Alms, Cincinnati 6, Ohio.

On Generalization of the Angular Momentum Equation

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Summary

The paper points out that the angular momentum equation of classical mechanics need not be restricted to the usual cases of origin of co-ordinates fixed or at the (accelerating) mass center. The origin can be arbitrary, and have an arbitrary motion, provided an additional term is included in the equation. This result is relatively unknown, although not completely so. It is shown by a simple example that if the motion of a point in the system is prescribed as a function of time, the choice of this point as origin in the general equation leads directly to the equations for the rotational rates, and the prescribed motion is automatically enforced.

Results

The equation considered is the familiar result of classical mechanics

$$\mathbf{M} = \frac{d\mathbf{H}}{dt}. \tag{1}$$

In this equation $\mathbf{M}$ equals the moment of the external forces, $\mathbf{H}$ equals the moment of momentum or angular momentum (for brevity) of the system, and $\mathbf{M}$ and $\mathbf{H}$ are to be calculated with respect to either: (a) a point fixed in inertial (Newtonian) space, or (b) the mass center of the system which, in general, is accelerating.

It is the purpose of the paper to demonstrate two results: (a) that Equation (1) can be generalized so that $\mathbf{M}$ and $\mathbf{H}$ can be computed with respect to an arbitrary point in the system, having an arbitrary motion, and (b) for the class of problems where the motion of one point in the system is prescribed as a function of time, use of the general equation leads to the scalar equations for the rotational rates more directly than the original Equation (1).

The generalized equation is

$$\mathbf{M}_o = \frac{d\mathbf{H}_o}{dt} + \mathbf{S}_o \times \mathbf{a}_o \tag{2}$$

where the arbitrary point is designated as point O and $\mathbf{S}_o$ equals static moment of the body with respect to point O, $\mathbf{a}_o$ equals absolute acceleration of point O, and $\mathbf{M}_o$, $\mathbf{H}_o$ have their original meanings but with respect to the point O. Before discussing the implications of Equation (2) we give first a brief proof.

Let us start from the original Equation (1) and choose the origin as the mass center. Also introduce the translation equation for the system. Thus

$$\begin{aligned} \mathbf{M}_c &= \dot{\mathbf{H}}_c \\ \mathbf{F} &= m\mathbf{a}_c \end{aligned} \tag{3}$$

where subscript c refers to the mass center and

$\mathbf{F}$ = resultant of the external forces
m = total mass of system
$\mathbf{a}_c$ = acceleration of the mass center.

Now with respect to an arbitrary point O having an arbitrary motion, the following transformations are valid:

$$\begin{aligned} \mathbf{H}_c &= \mathbf{H}_o - \boldsymbol{\varrho} m_o \times \dot{\boldsymbol{\varrho}}_o \\ \mathbf{M}_c &= \mathbf{M}_o - \boldsymbol{\varrho}_o \times \mathbf{F} \\ \mathbf{a}_c &= \mathbf{a}_0 + \ddot{\boldsymbol{\varrho}}_o \end{aligned} \tag{4}$$

where $\boldsymbol{\varrho}_o$ equals position vector from point O to the mass center.

Combining Equations (3) and (4)

$$\mathbf{M}_o - \boldsymbol{\varrho}_o \times m(\mathbf{a}_o + \ddot{\boldsymbol{\varrho}}_o) = \frac{d}{dt}(\mathbf{H}_o - m\boldsymbol{\varrho}_o \times \dot{\boldsymbol{\varrho}}_o)$$

or

$$\mathbf{M}_o = \dot{\mathbf{H}}_o + \mathbf{S}_o \times \mathbf{a}_o$$

which is Equation (2), with $\mathbf{S}_o = m\boldsymbol{\varrho}_o$.

Equation (2) is the desired result. Clearly, it contains the usual cases, point O chosen fixed or as the mass center as special cases, since in the former $\mathbf{a}_o = 0$, while in the latter $\mathbf{S}_o = 0$. Expanding Equation (2) for a rigid body and choosing xyz as principal axes with origin at point O, the result is set of "generalized Euler equations."

$$\begin{aligned} M_x &= I_x\dot{\omega}_x + (I_z - I_y)\omega_y\omega_z \\ &\quad + (S_ya_z - S_za_y) \\ M_y &= I_y\dot{\omega}_y + (I_x - I_z)\omega_z\omega_x \\ &\quad + (S_za_x - S_xa_z) \qquad (5) \\ M_z &= I_z\dot{\omega}_z + (I_y - I_x)\omega_y\omega_x \\ &\quad + (S_xa_y - S_ya_x). \end{aligned}$$

In these equations the components of $\mathbf{M}$, $\boldsymbol{\omega}$ and $\mathbf{a}$ are all to be evaluated in an inertial co-ordinate system instantaneously coincident with the body axes xyz. The first and second mass moments, the components of S and I, are evaluated with respect to the body axes and are constants of the problem. All terms in Equation (5) refer to point O so that the subscript can be omitted.

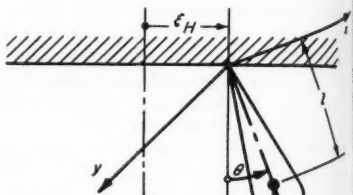
Equation (2) is derived in a few texts, e.g., Lass *Vector Analysis*, pages 197, 198 and Karman and Biot, *Mathematical Methods in Engineering*, pages 79 through 81. However, it does not appear in the standard works of Rutherford, *Classical Mechanics*, Lindsay *Physical Mechanics*, Timoshenko *Advanced Dynamics*, Synge and Griffith *Principals of Mechanics*, and Goldstein *Classical Mechanics*. Even in the former two references where the equation is presented, the implication is that application will be simplified if the origin is restricted to the cases of the fixed point or the mass center. Of course, this is generally true. However, in the next section it is shown by a simple example, that in fact, if the motion of one point in the body is prescribed as a function of time, Equation (2) or (5) is the more natural equation to use as the prescribed motion is then automatically enforced.

The same example is also treated in the conventional manner where the origin is chosen at the mass center. Naturally the final results are identical but the latter method leads to considerable additional calculation.

Example

Consider the planar motion of a physical pendulum, whose hinge point is being oscillated horizontally, according to

$$\xi_H = A \sin \omega t.$$



y axis perpendicular to plane of motion

Taking xyz axes fixed in the body as shown, the separate terms in Equation (5) are:

$$\begin{aligned} \mathbf{M}&: \quad M_x = M_z = 0; \quad M_y = -mgl \sin\theta \\ \boldsymbol{\omega}&: \quad \omega_x = \omega_z = 0; \quad \omega_y = \dot{\theta} \\ \mathbf{a}&: \quad a_x = \ddot{\xi}_H \cos\theta; \quad a_z = \ddot{\xi}_H \sin\theta; \quad a_y = 0 \\ \mathbf{S}&: \quad S_x = S_y = 0; \quad S_z = ml. \end{aligned}$$

Substituting this in Equation (5) with $\ddot{\xi}_H = -\omega^2 A \sin \omega t$, the first and third are identically satisfied and the second gives directly the equation of motion for θ:

$$\begin{aligned} I_y\ddot{\theta} + mgl \sin\theta \\ = (mlA\omega^2 \sin \omega t) \cos\theta \qquad (6) \end{aligned}$$

where I_y is about the hinge.

Conventional Method, Using Equations (3)

Write the translation equation for the motion of the mass center and rotation about it, introducing (unknown) forces at the hinge.

(*Continued on p. 255*)

Further Property of the Center of Percussion

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Consider the rigid body shown in Figure 1 which is symmetrical with respect to the plane of the paper and which has its mass-center at G, and which has a radius of gyration of $\bar{K}$ about the axis through G perpendicular to the plane of the paper. Point A is any point on the body in the plane of symmetry and $\bar{r}$ is the distance from A to G. Point P lies on the line AG at the distance $\frac{\bar{K}^2}{\bar{r}}$ from the mass-center G.

It is a well known fact that, if the body is attached to a shaft at A, a force at P which is in the plane of symmetry and which is perpendicular to the line AG will not cause a reactive force on the shaft. There is an additional interesting property as follows: *If the body has plane motion parallel to the plane of symmetry and if there is an impulsive force at A in this plane, the rectangular component of the velocity of P perpendicular to the line AG does not change as a result of the impact.*

Proof:

The body has an initial angular velocity of ω_0 and an initial linear velocity of the mass center of $\bar{V}_0$ in the directions indicated in Fig. 2(a). After the impulsive force at A, these quantities become ω and V as shown in Fig. 2(b). V_A, which is the velocity of point A after the impact, can have any magnitude and direction. Let the mass of the body be m. The moment about A of the initial momenta plus the moment about A of the impulse is equal to the moment about A of the final momenta.

Therefore:

$$(m\bar{V}_0)\bar{r}\cos\theta_0 + (m\bar{K}^2)\omega_0 = (m\bar{V})\bar{r}\cos\theta + m\bar{K}^2\omega$$

$$\therefore\ \bar{V}_0\cos\theta_0 + \frac{\bar{K}^2}{\bar{r}}\omega_0 = \bar{V}\cos\theta + \frac{\bar{K}^2}{\bar{r}}\omega.$$

But:

$$\text{Initial}\quad (V_P)_x = \bar{V}_0\cos\theta_0 + \frac{\bar{K}^2}{\bar{r}}\omega_0$$

and:

$$\text{Final}\quad (V_P)_x = \bar{V}\cos\theta + \frac{\bar{K}^2}{\bar{r}}\omega$$

$$\therefore\ \text{Initial}\ (V_P)_x = \text{Final}\ (V_P)_x.$$

The above principle can be used to obtain a quick solution to certain problems which are often considered in the usual undergraduate dynamics course for engineers. The following problem, which is taken from a recent quiz given to Lehigh students, will serve as an example.

The rod AB of Fig. 3 weighs W pounds and it moves on a horizontal frictionless surface. The initial linear velocity is 16 ft./sec. to the right, and the initial angular velocity is zero. Find the linear velocity of the mass center and the angular velocity after the end A collides with the rigid corner C. The coefficient of

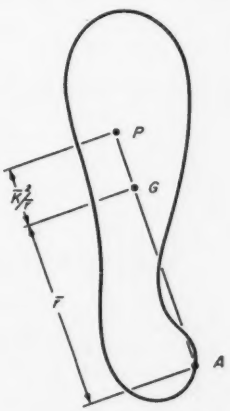
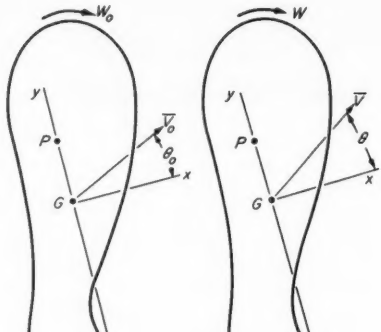


FIG. 1.



(a) Before impulsive force at A *(b) After impulsive force at A*

FIG. 2.

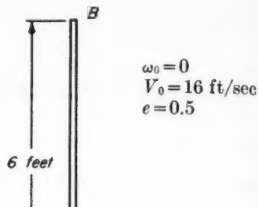


FIG. 3.

restitution, e, for this impact is 0.5.

$$\frac{\bar{K}^2}{\bar{r}} = \frac{\frac{1}{12}L^2}{\frac{1}{2}L} = \frac{L}{6} = 1 \text{ ft.}$$

$\therefore$ P is 4 feet from A.

After impact:

$$V_P = 16 \text{ ft./sec.}$$

and

$$V_A = -(0.5)16 = -8 \text{ ft./sec.}$$

$$\omega = \frac{16-(-8)}{4} = 6 \text{ rad./sec. clockwise;}$$

$$\bar{V} = -8 + 3(6) = 10 \text{ ft./sec.}$$

The propriety of presenting this method to undergraduate engineering students is debatable, since a great many of my students, at least, are all too eager to learn a short-cut method which saves them from the painful chore of applying the general impulse-momentum principles. For this particular quiz problem several of my students presented a short, quick, easy but erroneous solution by assuming that the upper terminal point B of the rod had the same velocity after impact as before. The reason for making such an assumption is a mystery to me. However, since several students did make this curious assumption, possibly students elsewhere may do the same thing. However, if the point of impact had been two feet above A, then the upper terminal point B would have been the center of percussion and its velocity would not be changed by the impact. Hence, it is important for the inventors of problems for quizzes and text-books to be aware of the fact that there does exist a point whose velocity component in a certain direction does not change as a result of the impact. Otherwise, they might be quite startled by a student's simple solution which yields the right answer.

NUCLEAR ENGINEERING EXPANDS AT NYU

The Graduate Division of New York University's College of Engineering will increase "the depth and scope" of its program in nuclear engineering beginning this fall, Dr. John R. Ragazzini, dean of the College, has announced.

Under the expanded program, the College will now offer the degree of doctor of engineering science for students majoring in nuclear engineering. Since 1955 it has granted the degree of master of nuclear engineering.

Variable–Mass Dynamics

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For the past 273 years following the publication in 1687 of Newton's *Principia*, scientists and engineers have carried out innumerable experiments and calculations based on the Second Law of Motion. It is difficult to think of any other physical law that has played a greater role in the description of physical problems, that has been subject to greater check, and that has afforded greater opportunity for adequate interpretation.

In view of this state of affairs it is interesting and somewhat startling to observe that this basic law of mechanics is currently being seriously misinterpreted. This misinterpretation appears under conditions where the mass of a body is a function of time. It is the purpose of this discussion to draw attention to this error and to indicate the correct formulation of the equations of motion for bodies whose mass varies with time.

A review of current references in basic and advanced mechanics discloses two different statements of the fundamental law. The first point of view presents

$$F = ma$$

for a particle (or body considered as a particle) of mass m subjected to a resultant force F and having an acceleration a. The second point of view presents

$$F = \frac{d}{dt}(mv)$$

as the basic or fundamental law where the resultant force equals the time rate of change of momentum. Clearly both formulations give identical results when the mass m is *not* a function of time. When m is a function of time, however, the statements differ by the term $v\,dm/dt$.

Presented before the Mechanics Division, Annual Meeting of A.S.E.E., Purdue University, June 21, 1960.

Many people accept the second point of view as the correct one for one or both of the following reasons. First, Newton said, "The change of motion is proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed." [1] Newton used the term "quantity of motion" to refer to the product of mass and velocity, so that by "change of motion" is meant the time rate of change of momentum. Second, with greater attention focused on vehicles with variable mass, the temptation to write $d(mv)/dt$ is very great in order that m may be treated as a variable with a time derivative. With all due respect to the genius of Newton, it can hardly be considered that he was thinking of the possibility of variable mass at the time of his formulation. Furthermore one is not justified in using a literal interpretation of a statement which is now historical as the correct formulation of problems for which the historical statements were not intended.

At this point it will be well to refer to the restrictions which govern the derivation of the equation $\sum F = \dot{G}$ as applied to a mass system where $\sum F$ is the resultant external force on the system and $\dot{G}$ is the time rate of change of the linear momentum of the system. The system S is defined at any instant of time t as the sum of the particles of mass within an envelope which defines the boundaries of S. At time t there are n particles in S, and the mass of the i^{th} particle is m_i. The mass of each individual particle is considered constant. With respect to a fixed Newtonian frame of reference, the center of mass of S at time t is found by the principle of moments, and its x-co-

[1] *Principia in Modern English*, Translation by F. Cajori, University of California Press, pp. 13, 645.

ordinate is given by

$$m\bar{x} = \sum_{i=0}^{n} m_i x_i \qquad (1)$$

where

$$m = \sum_{i=0}^{n} m_i.$$

Differentiation of Eq. (1) with time yields

$$m\dot{\bar{x}} = \sum_{i=0}^{n} m_i \dot{x}_i = G_x \qquad (2)$$

where G_x is defined as the linear momentum of S in the x-direction. A second differentiation yields

$$m\ddot{\bar{x}} = \sum_{i=0}^{n} m_i \ddot{x}_i = \dot{G}_x. \qquad (3)$$

In each of these steps the total mass m was treated as *constant*. Thus when the force-mass-acceleration equations for all particles are added and internal forces cancelled, the resultant external force on the system is

$$\sum F_x = \sum_{i=0}^{n} m_i \ddot{x}_i \quad \text{or} \quad \sum F_x = \dot{G}_x. \qquad (4)$$

It should be quite clear that Eq. (4) is derived on the basis of *constant* total mass of the system.

Equation (4) can be used to analyze variable mass systems only if applied to an entire system of constant mass having two or more parts among which interchange of mass occurs. Thus if a constant total mass m is divided into two distinct parts m_1 and m_2, each moving with velocities v_1 and v_2, we may write for the forces external to m

$$\begin{aligned}\sum F_x &= \frac{d}{dt}(m_1 v_1 + m_2 v_2) \\ &= m_1 \dot{v}_1 + m_2 \dot{v}_2 + \dot{m}_1 v_1 + \dot{m}_2 v_2 \\ &= m_1 \dot{v}_1 + m_2 \dot{v}_2 + \dot{m}_1 (v_1 - v_2) \qquad (5)\end{aligned}$$

since $\dot{m}_2 = -\dot{m}_1$. Equation (5) may be applied as a very close approximation[2] to the motion of a rocket where m_1 represents the mass of the rocket machinery and fuel and m_2 the mass of an arbitrary segment of expelled exhaust mass. Neglecting any acceleration of the exhaust stream once clear of the nozzle, $v_2 = 0$, and Eq. (5) may be written

$$\sum F_x = \frac{d}{dt}(m_1 v_1) - v_2 \dot{m}_1 \qquad (5A)$$

where $\sum F_x$ then defines the external force summation on the rocket. It is clear that for this variable mass system $\sum F_x \neq \dot{G}_x$.

In order to derive the correct linear momentum equation for a variable mass it is necessary to treat m as a function of time. This is accomplished by allowing an increment of mass Δm to enter a section of the envelope of S during time Δt. In Fig. 1 the coordinate to this entrance section is x_e, and the coordinate to the last particle of Δm to enter S in time Δt is x_p. The coordinate to the center of mass of Δm is x_0. The location $\bar{x}$ of the center of mass of the n particles of S at time t is given by

$$\bar{x}m = \sum_{i=0}^{n} m_i x_i$$

whereas at time $t + \Delta t$ this becomes

$$\bar{x}m + \Delta(\bar{x}m) = \sum_{i=0}^{n} m_i (x_i + \Delta x_i) + \Delta m (x_0 + \Delta x_0).$$

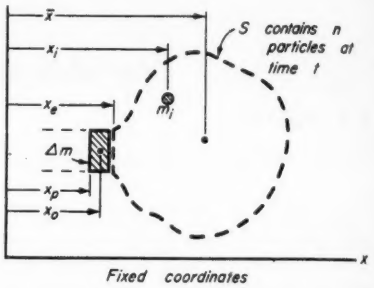

FIG. 1.

[2] It may be shown that the approximation contains the assumption that the distance between the center of mass of the rocket and the nozzle is small and has negligible time derivatives. In this connection see the paper "On the Equation of Rocket Motion," by G. Leitmann, *Journal of the British Interplanetary Society*, July–September, 1957, **16**(3), pp. 141–147, in which the correct equations are derived.

Subtracting the first from the second equation, dividing by Δt, passing to the limit, and neglecting the second-order term give

$$\frac{d}{dt}(\bar{x}m) = \sum_{i=0}^{n} m_i\dot{x}_i + x_0\dot{m}.$$

Substituting the definition of the linear momentum of S from Eq. (2) gives

$$G_x = \frac{d}{dt}(\bar{x}m) - x_0\dot{m} = m\dot{\bar{x}} + (\bar{x} - x_0)\dot{m}. \quad (6)$$

Hence we see that the linear momentum of a variable mass depends on the location of the entrance section with respect to the mass center.

The derivative of G_x is obtained by writing the increment in momentum starting from the definition of G_x in Eq. (2). Thus, at time $t + \Delta t$

$$G_x + \Delta G_x = \sum_{i=0}^{n} m_i(\dot{x}_i + \Delta\dot{x}_i) + \Delta m(\dot{x}_0 + \Delta\dot{x}_0)$$

where the momentum of Δm must now be included. Subtracting Eq. (2), dividing by Δt, passing to the limit, and neglecting the second order term yield

$$\dot{G}_x = \sum_{i=0}^{n} m_i\ddot{x}_i + \dot{x}_0\dot{m}. \quad (7)$$

Writing the force-mass-acceleration equation for each particle of S at time t and adding them together give for the summation over S

$$\sum F_x = \sum_{i=0}^{n} m_i\ddot{x}_i.$$

From Eq. (7) this expression becomes

$$\sum F_x = \dot{G}_x - \dot{x}_0\dot{m} \quad (8)$$

which is the correct force-momentum equation for a variable-mass system. The interpretation of $\dot{x}_0$ must be carefully observed. It is the coordinate of the mass center of Δm which decreases from Δm to zero during Δt. Thus

$$x_0 = \tfrac{1}{2}(x_e + x_p) \quad \text{and} \quad \dot{x}_0 = \tfrac{1}{2}(\dot{x}_e + \dot{x}_p)$$

which shows that $\dot{x}_0$ is the average between the velocity of the entrance section and the velocity of the approaching particles.

The results only of application of Eq. (8) to an ascending rocket will be cited as a concluding statement.

Let m = mass of rocket machinery and fuel at time t, $m = W/g$
θ = angle of rocket axis from the horizontal
p = mean static pressure of exhaust gases across the nozzle exit plane
A = area of exit plane
U = relative velocity of escaping gases with respect to the rocket
R = aerodynamic drag along rocket axis
h = distance from nozzle exit plane to center of mass of rocket.

With these symbols, it may be shown that Eq. (8) gives

$$-U\dot{m} + pA - W\sin\theta - R = m\ddot{x}_e + \frac{d^2}{dt^2}(mh).$$

It is the last term which has been missed in the derivation of the linear equation of motion for a rocket. Fortunately the magnitude of this last term is negligible for present rockets but may be important in some other applications.

FACULTY UTILIZATION RESEARCH

The Educational Methods Division has announced a three day invitational conference on Research on Faculty Utilization, January 9, 10, and 11, at the Westinghouse Educational Center in Pittsburgh. It has grown out of the CDEF report presented to the Society last year. The purpose of this conference is to summarize and evaluate the current research on faculty utilization and discuss its application to current problems in engineering education.

For additional information contact Edward J. Rising, Department of Mechanical Engineering, University of Massachusetts, Amherst, Massachusetts.

Candid Comments

ERIC A. WALKER [1]

I should like to take this opportunity to ask some questions and to share with you some thoughts I have had about the future of ASEE and its operation.

In the first place, I should like to ask, who actually runs the Society? The General Council is supposed to run it, but I sometimes wonder whether the Council is really the governing body. It isn't the right size to serve this function. In fact, it more nearly serves as a board of approval. There is very little discussion in the Council on the direction of the Society, and, consequently, it isn't a board of directors. There is, of course, a planning committee, but it hasn't so far proved to be very effective.

A question now often asked is whether ASEE should go "big time." This should be a matter of discussion in the General Council. In this discussion, the Council should recognize that there are related questions. What about the location of the headquarters, for instance, and its staffing? Should any change be made in these things?

There also has been talk about councils. Should the Technical Institute Division be a council? Should the Relations With Industry Group? Who considers whether we need two, four or six councils? And how about divisions and sections? Should there be changes in this area? For example, should the National Capital or Allegheny Sections be abolished?

The next meeting of the General Council will be called prior to the next meeting of the Executive Board. For this meeting, I am going to ask that reports be sent in beforehand so that there won't be a lot of papers around at the meeting in order that we can spend time discussing what ASEE should be doing. For this preliminary work, I will select people to prepare statements and ask the Planning Committee to make long-range plans.

I should like to ask all representatives of the sections and divisions to take a critical look at what you are doing and what your functions are in advance of the next meeting. For example, the Educational Methods Division is not satisfied with its title, its members believing that the Division should be more of an engineering-teaching research group. The Relations With Industry Division is convinced that its usefulness will be enhanced by closer integration with the Society. Perhaps the Industrial Membership Committee should be a part of RWI, and perhaps RWI should work with the Graduate Studies Division on mutual problems.

Someone also should be doing some thinking about the presidency of ASEE. Sould the incoming president be designated earlier than he is at the present time? Perhaps we should have an executive vice president for one year who could then take over as president the following year, or perhaps we should have a full-time president. Certainly, more continuity is needed in this office.

The Committee on Development of Engineering Faculties has been one of the most successful committees of the Society, and its operations will bring much credit to the Society. The Committee, under the chairmanship of Dr. H. L. Hazen, devoted much time to its project and had a full-time man working on it. The Committee believes it should now be terminated, and it suggests that the work be continued in the following way:

1. The whole concept of further work on recruiting faculties be taken over by ECAC.

[1] At the final meeting of the General Council last June President-elect Eric A. Walker asked for permission to make some comments. Since they seem so pertinent to the future of ASEE and to all ASEE's members they are published here in full.

2. The development of faculties be taken over by a new Society committee.
3. The utilization of faculties be handled by the Educational Methods Division.

I am appalled at the growth of our annual meetings. Increasingly, more and more sessions take more and more time. Some members have told me the general sessions were excellent but there should be more discussion. Some also have said that they thought division meetings ought to be held in the afternoons on the same sort of themes as the general sessions. We have an Annual Meeting Committee that makes recommendations for the location of future annual meetings and that considers the sufficiency of facilities at prospective host institutions. Could we develop a better plan for annual meetings? If anyone has ideas about these matters, I should like to ask him to communicate with Dr. N. A. Hall, the new chairman of the Annual Meeting Committee.

I now am going to ask your approval, as a matter of policy, of an action taken by the Executive Board. The proposal develops from the growth of interest in research in engineering education. The Society is developing projects of all kinds, and some people from outside ASEE say that the Society is not doing enough—that we should not have a lot of small projects but rather one big one.

I would like for this General Council to approve the formation of a "Project Management Committee," the function of which would be to initiate proposals for study and research in engineering education for approval of the General Council and Executive Board. After this approval, the Committee would then submit them to foundations for consideration. The Committee would also choose project directors, see that the project accomplishes its mission, and transmit the results to appropriate groups for implementation. The Executive Board has approved $5,000 for one year in operating funds to get the project under way, the money coming from the unallocated reserve.[2]

[2] The motion was made, seconded, and passed by the General Council at its meeting on June 24, 1960.

AEC FELLOWSHIPS

Students in chemistry, engineering, mathematics, or physics may receive the financial means to pursue graduate studies under Atomic Energy Commission Special Fellowships in Nuclear Science and Engineering.

Up to 150 fellowships are available, for first-, intermediate-, and terminal-year graduate study at a school selected by the fellow from a list of more than 50 designated universities.

First-year graduate students receive $1800 for twelve months, intermediate-year students receive $2000, and terminal-year students receive $2200. An additional $500 is allowed for a spouse, and $500 each for a maximum of two dependent children. Tuition, fees, and a limited travel allowance are also provided. First- and intermediate-year fellowship may be renewed for a total of three years of fellowship support; applicants for fellowship renewal will be considered on an equal basis with other applicants.

Duration of the fellowship is twelve months, although intermediate- and terminal-year fellows may reduce the term to one academic year with an appropriate adjustment in stipend payment.

Graduate students, or seniors who will have received their degrees by the beginning of the 1961–62 academic year may apply for a fellowship to begin in the fall of 1961. Applications must be received by January 6, 1961.

Further information and application blanks for these fellowships are available from the Nuclear Science and Engineering Fellowship Office, Oak Ridge Institute of Nuclear Studies, P.O. Box 117, Oak Ridge, Tennessee.

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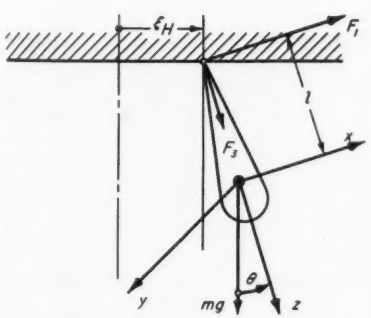
On Generalization of the Angular Momentum Equation

(*Continued from p. 238*)



The xyz axes are again fixed in the body, but the origin is now at the mass center. Resolving the hinge force into components F_1 and F_3 along the x and z axes, the Euler equations give

$$-F_1 l = I_{y_c}\ddot{\theta}. \tag{7}$$

To determine F_1, introduce the translation equations for the mass center

$$\begin{aligned} F_1 - mg\sin\theta &= ma_{x_c} \\ F_3 + mg\cos\theta &= ma_{z_c} \end{aligned} \tag{8}$$

with the kinematic restraints

$$\begin{aligned} &a_{x_c}\cos\theta + a_{z_c}\sin\theta - l\ddot{\theta}\cos\theta \\ &\quad + l\dot{\theta}^2\sin\theta = \ddot{\xi}_H = -\omega^2 A\sin\omega t \\ &a_{x_c}\sin\theta - a_{z_c}\cos\theta - l\ddot{\theta}\sin\theta \\ &\qquad - l\dot{\theta}^2\cos\theta = 0. \end{aligned} \tag{9}$$

Substituting Equation (9) into (8) and solving for F_1:

$$\begin{aligned} F_1 = &-m\omega^2 A\sin\omega t\cos\theta \\ &+ ml\ddot{\theta} + mg\sin\theta \end{aligned} \tag{10}$$

and using Equation (10) in (7) and noting that

$$I_{y_c} = I_y - ml^2$$

gives Equation (6) precisely.

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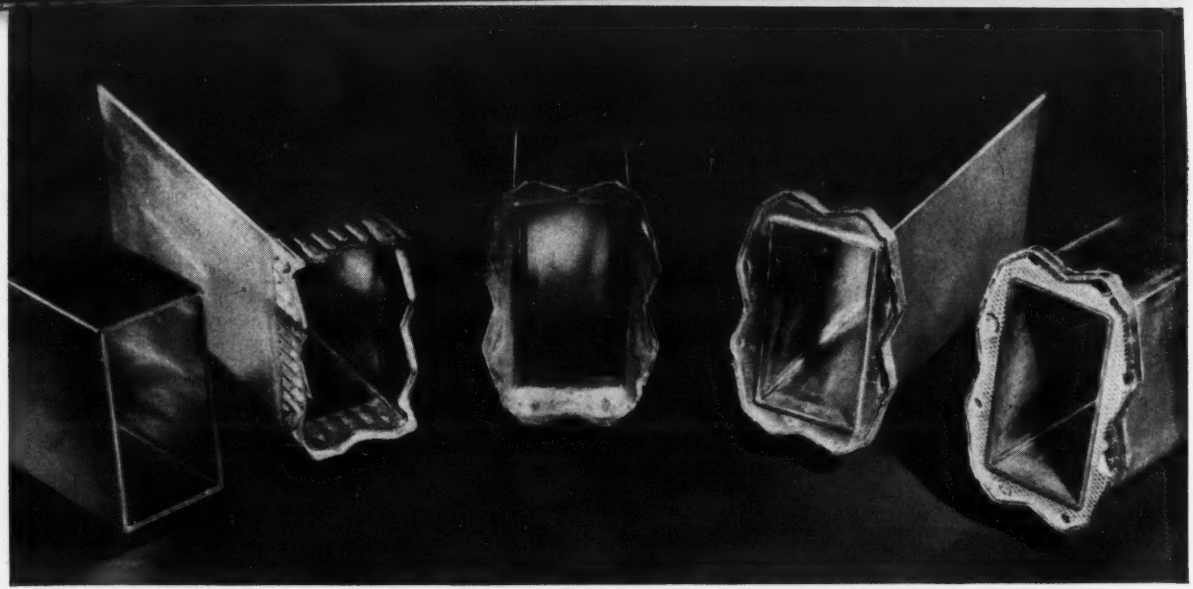

1 Waveguide cross-section before cold-flanging process.

2 First punch gathers the copper under extreme pressure.

3 The second starts flaring the metal to form eventual flange.

4 The third punch flattens copper into shape of finished flange.

5 The fourth embosses and completes flange. Time: approx. 50 sec.

Making cold copper flow like liquid

Waveguides — the metal tubes which carry microwave signals between an antenna and its transmitter or receiver — are used extensively in military radar and in the transmission of long distance telephone calls by

and lost its strength. The solution was to make the copper flow without heat — to crush it at such great pressure that the end of the tube would fold back and out in a fluid movement — *and do so without changing the*

Making cold copper flow like liquid

Waveguides — the metal tubes which carry microwave signals between an antenna and its transmitter or receiver — are used extensively in military radar and in the transmission of long distance telephone calls by radio relay. They must be manufactured to precise specifications, since a variation of only .003" in their interior dimensions will cause serious microwave distortion.

This problem is complicated by the fact that as many as 100 individual waveguides may be used in connecting radio equipment with its antenna. Thus, not only must the waveguides be precisely engineered, but the connecting points must be constructed so that they offer no interference with the interior dimensions.

Connecting two or more waveguides is accomplished by use of flanges, or rims, on the ends of the tubes. Formerly, these flanges were separately manufactured and manually joined to the waveguides. The process was slow and costly, so Western Electric engineers developed a means of forming the flanges from the ends of the waveguides themselves. In doing so, they accomplished a metallurgical feat never before approached.

As a first step, the possibility of heating the waveguides and molding the ends into flanges was tried. This idea was not pursued since the heated copper annealed and lost its strength. The solution was to make the copper flow without heat — to crush it at such great pressure that the end of the tube would fold back and out in a fluid movement — *and do so without changing the inside dimensions of the tube.*

Development centered around the design of four high-precision forming punches with two complementary forming dies. Each punch was planned to take a step in the redistribution of the copper, with the dies acting as forming molds. To achieve the exact pressure and punching sequence required, it was necessary to design and build a special hydraulic press.

Here's how the process works: A waveguide is held in a fixed position in the press while the punches move in, out, and around, controlled by a revolving index head. The result of each punching stage is illustrated above.

This is believed to be the first time that precision metal tubing has been cold-flanged without distorting its configuration, and the first time that anyone has automatically produced waveguide flanges. The savings in time, labor and materials are substantial.

This break-through in metal-working, with all its many possibilities in other fields, is another example of Western Electric's progress in engineering developments.

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Section Meetings

Section	*Location of Meeting*	*Dates*	*Chairman of Section*
Allegheny		April, 1961	E. R. Schatz, Carnegie Institute of Technology
Illinois-Indiana	Ill. Inst. of Tech.	May 13, 1961	Peter Chiarulli, Ill. Inst. of Tech.
Kansas-Nebraska	Kansas State U.	Oct., 1961	M. H. Snyder, Univ. of Wichita
Michigan	Michigan State U.	April 22, 1961	C. E. Cutts, Mich. State Univ.
Middle Atlantic	Drexel Inst. of Tech.	Dec. 3, 1960	F. L. Singer, New York Univ.
Missouri-Arkansas	Saint Louis Univ.	April 8, 1961	V. T. Allen, Saint Louis Univ.
National Capital Area		Jan. 10, 1961	Geo. H. Hickox, Ft. Belvoir, Va.
New England	Brown University	Oct., 1961	E. F. Littleton, Tufts Univ.
North Midwest	Marquette Univ.	Oct., 14–15, 1960	R. J. Kipp, Marquette Univ.
Ohio	Ohio State Univ.	April, 1961	R. S. Green, Ohio State Univ.
Pacific Northwest	Univ. of Washington	May, 1961	H. P. Mittet, Univ. of Washington
Pacific Southwest	Stanford University	Dec. 28–29, 1960	R. J. Parden, U. of Santa Clara
Rocky Mountain	University of Wyoming	Apr. 28–29, 1961	A. J. McGaw, Univ. of Wyoming
Southeastern	Univ of Mississippi	April 20–21, 1961	W. J. Seeley, Duke Univ.
Southwest	Univ. of Tulsa	Apr. 7–8, 1961	G. B. Tims, Jr., Lamar State College
Upper N. Y.-Ontario	Clarkson College		R. D. Larsson, Clarkson College

Mid-Winter Meetings–1961

Cooperative Education — Jan. 23–25 — University of Detroit

Information: D. C. Hunt, Director of Coordination and Placement, University of Detroit, Detroit, Mich.

Engineering Graphics — Jan. 19–21 — University of Wichita

Information: A. C. Risser, Head, Engineering Drawing, University of Wichita, Wichita, Kansas

College-Industry Conference — Feb. 2–3 — University of Cincinnati

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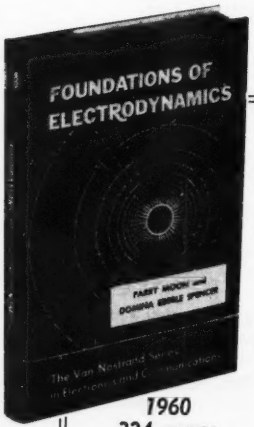

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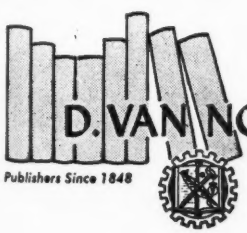

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